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BE in CPPS

Innovation Action Project

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D2.7 Smart Systems Platform Federation – Accompanying document

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Executive Summary

The BEinCPPS Reference Architecture, proposed in Deliverable D2.1, is divided into three main levels, namely the Cloud Level, Factory Level and Field Level, whereby each level focuses on different aspects of Cyber-physical Production Systems (CPPS). This document reports on the individual components identified on the Field Level in the BEinCPPS Reference Architecture. The Field Level is the lowest level in the architecture, encompassing both hardware and software components. Embedded systems (field computation) and real-time networks (field communication) are the two main topics covered on this level.

The components identified at the field level are loosely coupled and can be applied as stand-alone parts by the end users (industrial champions or partners coming from the open calls), whereby nevertheless the target of the field level is to apply the different components in a combined version. The partners responsible for the components are therefore also striving towards an integrated version of the different components, especially aiming at real-time communication between the components at the field level.

A selection of the components at the field level are already available at their respective owners (i.e. partners in the BEinCPPS project) and are made available in the project as background knowledge. These components are immediately available at the submission of this deliverable. During the course of the project, among other based on feedback from the industrial champions and new partners coming from the open calls) will influence the developments on the components and will finally be made available as foreground knowledge to the project. The foreground knowledge the partners are aiming at, is presented in this deliverable in their respective annexes in extensive factsheet, thereby providing sufficient information towards potential users of the technologies.

A separation of the components with respect to availability will be presented in the deliverable. A selection of the field level components are available as open source, whereas components coming from industrial companies will be provided as proprietary hardware and on software level only binary versions.

Finally, the deliverable provides guidelines and motivation for the potential technology users for selecting and applying the identified technologies in their applications.

1. Introduction

1.1. Objective of the Deliverable

Deliverable D2.7 describes the Smart Systems Platform introduced in Deliverable D2.1. Within the Smart Systems Platform various components are identified that are of interest to the development of Cyber-physical Production Systems (CPPS). This deliverable will provide a detailed description of the components, starting from their current version available (background knowledge for the BEinCPPS projects) and advancing towards the upcoming developments in a second phase of this deliverable (foreground knowledge).

During the course of the BEinCPPS project, the Smart Systems Platform is continuously under development and will be delivered in two phases during the project. In the first phase, which is due with the deliverance of this document, first

versions of some of the components of the platform will be provided, with which the champions and partners coming from the first open call can perform first implementations and experiments. Based on the feedback from the first iteration, adaptations will be made to the components in the platform. This adaptations and new developments will again be made available to the champions and additionally, to new partners in the project resulting from the upcoming open calls in the BEinCPPS project.

1.2. Structure of the Deliverable

The document starts with a short introduction of the Smart Systems Platform (which is described in more detail in deliverable D2.1 – BEinCPPS Architecture and Business Processes) and positioning the Smart Systems Platform into the overall BEinCPPS architecture as defined so far (section 2.1). Continuing, an overall image is sketched of the individual components available within the Smart Systems Platform and how they are related to each other (section 2.2). Here, also a differentiation is being made between the components that are available as an open source variant and which are proprietary components.

Section 3 identifies the individual components within the Smart Systems Platform in more detail. The components will be divided between background and foreground components and additionally again, the differentiation between open source and proprietary components. As the foreground components are the more interesting parts with respect to the development in BEinCPPS, extensive factsheets of these are added in the Appendix where the foreground components are explained in larger detail. The factsheets contain among others a detailed description of the components, specific development related to BEinCPPS, HW/SW prerequisites, operator instructions and references to manuals and tutorials. Section 3 concludes with guidelines for selecting the developed components, with the goal to alleviate the potential technology users and industrial champions within the BEinCPPS project in choosing the appropriate technology for this applications.

Finally, section 0 concludes the deliverable.

1.3. Applicable Documents

[DOA]: Description of Actions for the BEinCPPS project, providing the basis for the entire project and this deliverable content

[D2.1]: BEinCPPS Architecture and Business Processes, Identification of the Smart System Platform

2. Architecture of the Smart Systems platform federation

2.1. Introduction and positioning in the overall BeInCPPS architecture

The BEinCPPS architecture is a definition of a three-layered implementation, which federates the most prominent Smart Systems, IoT and Future Internet platforms. This document focuses solely on the Smart Systems platform federation. IoT and Future Internet (FI) are handled in deliverables D2.3 and D2.5.

The Smart Systems platform federation is placed at the shopfloor/field level in the BEinCPPS approach (see Figure 1), which is located at the lowest level, containing both hardware and software assets. Embedded systems (field computation) and RealTime Networks (field communication) are the two topics that are covered in the Smart Systems Architecture. To the embedded systems belongs the BEinCPPS µCEP,

which is a downsized porting of the FITMAN DyCEP software component. This part runs on Linux-capable boards, like e.g. RaspberryPI, and network appliances. Another asset contained in the embedded systems is the 4DIAC RTE (Runtime Environment), which is a portable implementation of the IEC 61499 environment for embedded control devices (CPUs). Furthermore, field communication is tackled by the TimeTriggered Ethernet (TTEthernet or TSN), which is a deterministic Ethernet implementation.
Finally, interoperability/management adapters are integrated for the most popular communication protocols for IoT and industrial automation. OPC UA will be supported by the deterministic Ethernet implementation.

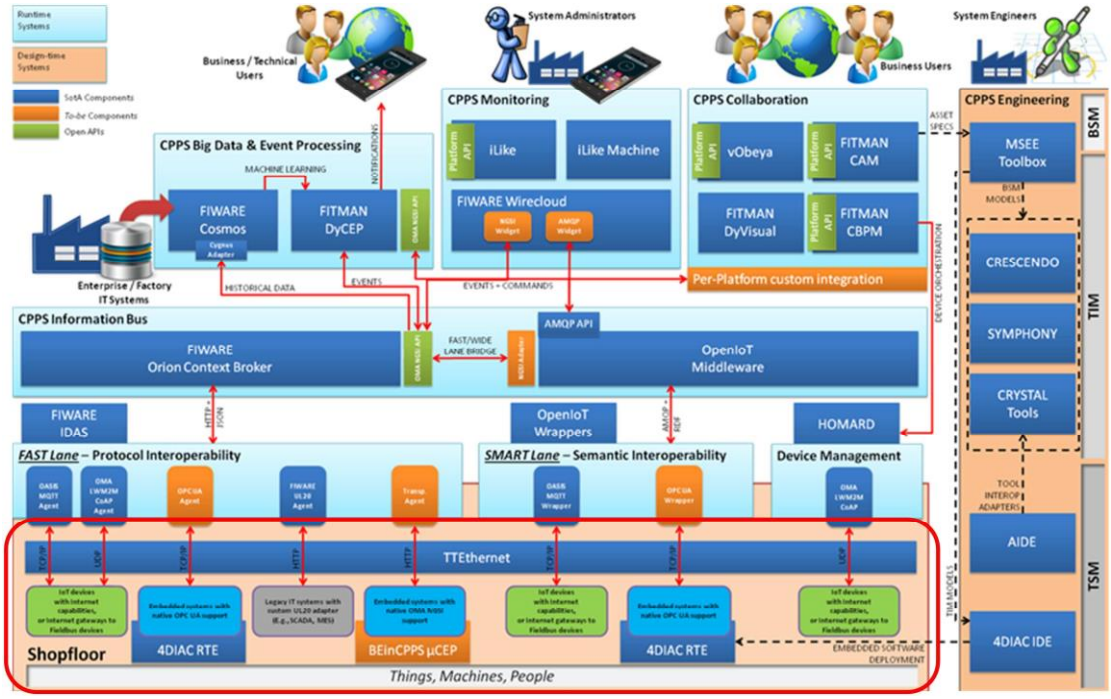

Figure 1: BEinCPPS Platform Overview

2.2. Smart Systems federation architecture

2.2.1. Requirements on the Smart Systems Federation Architecture

The Smart System Federation Architecture is responsible for the CPS-ization (see deliverable D2.1) of the factory, what can be identified as the transformation of the field level towards more intelligent, active devices. For an architecture to perform CPS-ization at field level, it has to fulfil certain requirements to be applicable. The following requirements are identified for the Smart System Federation Architecture:

- Lightweight – To avoid too large complexity, it is advised to keep the Smart System architecture as lightweight (i.e. as small) as possible, but on the other hand make sure that all industrial requirements are uphold.
- Real-time Communication – For CPPSs to be able to interact with each other within a deterministic manner, real-time communication is mandatory. In many industrial processes, control data on the shop floor coming from sensors must arrive in a deterministic way at the corresponding actuators to guarantee the behaviour of the industrial system. Real-time communication upholds these requirements.

- Shop Floor – The architecture needs to be defined with the industrial shop floor as main target area. The technologies identified for the architecture are all aimed for usage in industrial manufacturing.
- Generic – The technologies applied and developed in the architecture must be interoperable, enabling easy interaction with other legacy technologies and components.
- Background Technology – To uphold the before mentioned requirements, the partners within the Smart Systems Architecture have been identified in such a way, that their background technology fits the concepts defined for the architecture.

2.2.2. Actual Smart Systems Federation Architecture

The initial version of the Smart Systems Federation Architecture consists of different background and foreground components (as depicted in Figure 2) of which some are provided as open source and other as proprietary components.

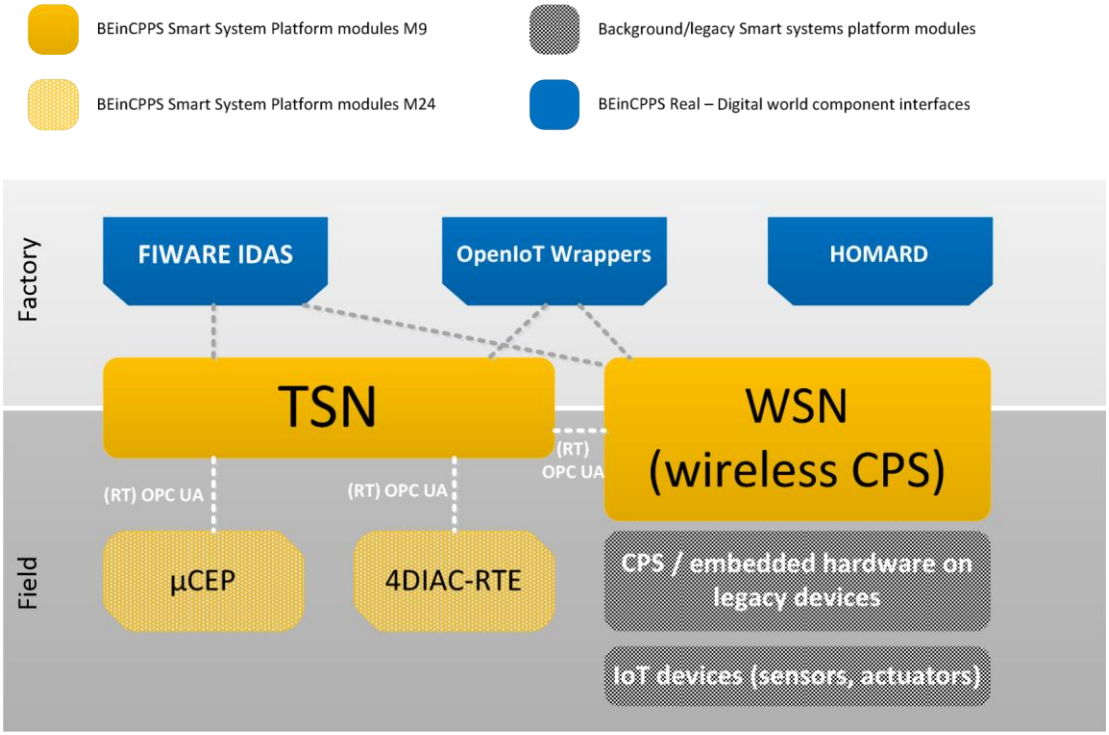

Figure 2: Smart Systems Federation Architecture

The following components are identified within the Smart Systems Federation Architecture:

- Time-Sensitive Networking (TSN) with (real-time) OPC-UA support
- 4DIAC Runtime Environment (FORTE)
- BEinCPPS µCEP
- Wireless Sensor Networking (WSN)

The components within the Smart Systems Architecture are loosely coupled components that have no dependencies to each other and can be applied individually from each other. The aim of the architecture is to provide a set of subsystem on the shop floor, enabling technologies requested by the industry, like e.g. real-time

support, real-time connectivity, intuitive embedded systems programming and (realtime) wireless communication. The individual components in the architecture target these requirements and provide the technologies as a collection of functionalities available to the industrial users. The end-users (e.g. system designers or integrators) can then identify and apply the technologies required by the application.

The individual components are described in the following sections, separating them into open source and proprietary components and additionally in background and foreground components.

3. Components

In this section, details about the selected components are provided, possibly with guidelines on how to operate a choice among them. Components are distinguished between those ones that have been enriched with foreground developments specific for the BeInCPPS project, from those ones that are made available in the platform as pre-existing assets, without specific adaptation for the BeInCPPS platform. Moreover, components are distinguished among those ones provided under Open source licences and the ones that are available under commercial licences.

3.1. Background components

3.1.1. COTS CPS components and IoT devices

Cyber-physical Systems (CPS) are systems composed of physical entities controlled or monitored by computer-based algorithms, general constituted from embedded computers and communication networks. Embedded computation is the core part of the CPS.

During the design of CPS components, different design practices have to be taken into account, ranging from software design to mechanical engineering.

IoT devices are also related to COTS CPS components. This comprises sensors and other devices that are present as legacy elements at the field level and that can be directly adapted, by configuration or software updates, to interact directly with the digital world.

In this component, we can find also CPS with wireless interfaces supporting IEEE 802.15.4 standards that can be used without the foreground enhancements provided by the WSN component of section 3.2.1.

Currently, many COTS CPS components are already available. An extensive research has been performed to give an overview of components available on the market. The results of this can be found in Appendix 1.

3.1.2. Open source components

4DIAC – Framework for Distributed Industrial Automation and Control

4DIAC is an exponent of the engineering methods implementing the technology behind IEC 61499[1]. IEC 61499 defines a domain specific modelling language for applications in the domain of distributed industrial control software. The underlying basic concept is that of event-driven function blocks. To bring modularity and reuse, function blocks are decoupled by means of adapter interfaces. The dynamic interface behaviour is described by means of service sequence diagrams.

4DIAC is an open source initiative founded in 2007 by PROFACTOR GmbH and the Automation and Control Institute (ACIN) of the Vienna University of Technology. Its goal is to provide an open IEC 61499 compliant environment and to foster the cooperation between automation research and its adoption in industrial areas like

[1] IEC SC65B. IEC 61499-1: Function blocks for industrial process measurement and control systems – Part 1: Architecture. Geneva. International Electrotechnical Commission, 2012.

manufacturing, logistics, building automation, or power and energy systems. The 4DIAC initiative is also meant to serve the further development of IEC 61499.
Currently, 4DIAC builds upon two main blocks: (i) 4DIAC Run-Time Environment (FORTE), a modular IEC 61499 compliant runtime environment for small embedded devices implemented in C++; and (ii) 4DIAC Integrated Development Environment (4DIAC-IDE), a modular IEC 61499 compliant engineering tool based on the Eclipse open tool framework. 4DIAC provides as well a library of IEC 61499 compliant function blocks usable for different kinds of automation tasks, a set of example and tutorial projects. In accordance to IEC 61499, the constituting 4DIAC elements are:

- *Systems* for describing the configuration of applications
- *Devices* representing hardware devices such as a programmable logic controller (PLC) or microcontrollers
- *Resources* are responsible for the execution of the control logic within their own execution contexts
- *Applications* contain the desired application in terms of a function block network - *Function blocks* (FB) are of the following types:
    - Basic: use an execution control chart (ECC) to control event execution. Algorithms are associated with the different states inside an ECC.
    - Composite: contain a FB network of existing FBs.
    - Service interface: used for something that cannot be done through the IEC 61499 standard like communication with devices or networks segments.
- *Adapter*s combine input/output events and data to one connection.

FORTE is a small portable multi-threaded C++ implementation of an IEC 61499 runtime environment targeting small embedded control devices. FORTE supports all IEC 61131-3 edition 2 elementary data-types, structures, and arrays. Applications can consist of any IEC 61499 element as basic function blocks, composite function blocks, service interface function blocks, adapters and subapplications. For connections between function blocks, FORTE uses automatic and safe castings (e.g., INT -> REAL). FORTE provides a flexible communication infrastructure via so called communication layers. FORTE has been tested on: Windows Cygwin on i386, ppc and xScale Linux on i386, ppc and xScale NetOS RTOS on IPC@chip eCos ARM7.

4DIAC-IDE is an Eclipse plugin which provides an extensible engineering environment for modelling distributed control applications compliant with IEC 61499. 4DIAC-IDE makes it easy to create new applications in a modular way by reusing existing function blocks from standard libraries. A snapshot of 4DIAC-IDE is shown in Figure 3. As it is depicted in Figure 4, the modelled applications can be downloaded to FORTE powered control devices according to the means defined by the “IEC 61499 Compliance Profile for Feasibility Demonstrations”. For testing, 4DIAC-IDE provides monitoring and debugging facilities to “watch” events and data values during execution. One can also interact with the application by changing or forcing data to have certain values, and by triggering events.

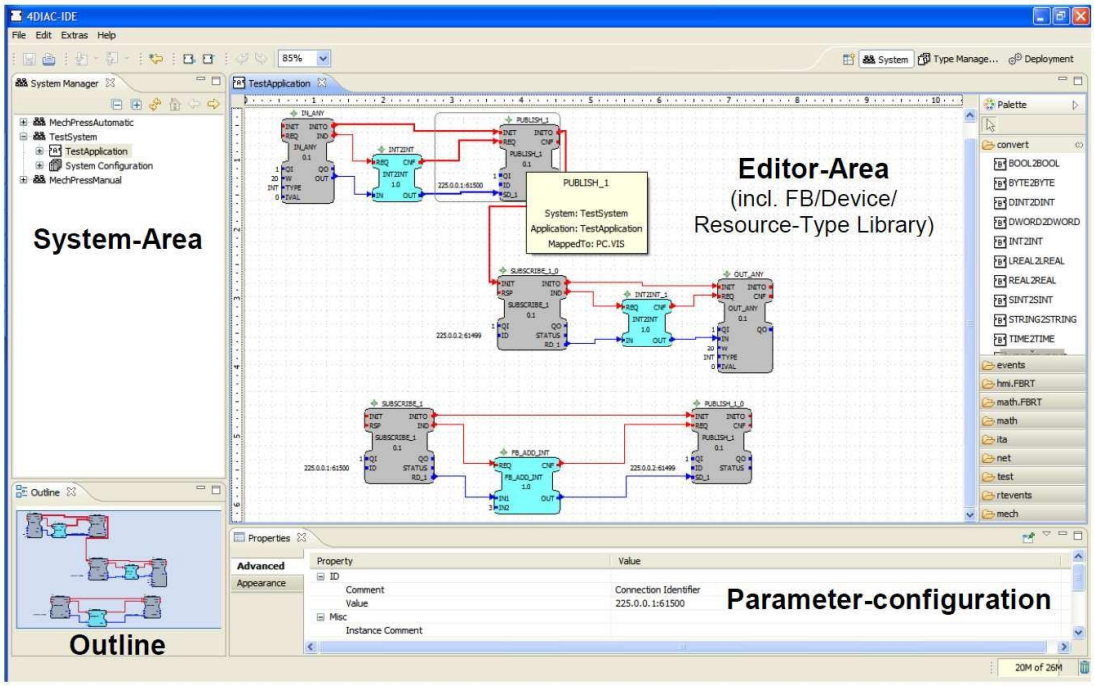

Figure 3: 4DIAC-IDE

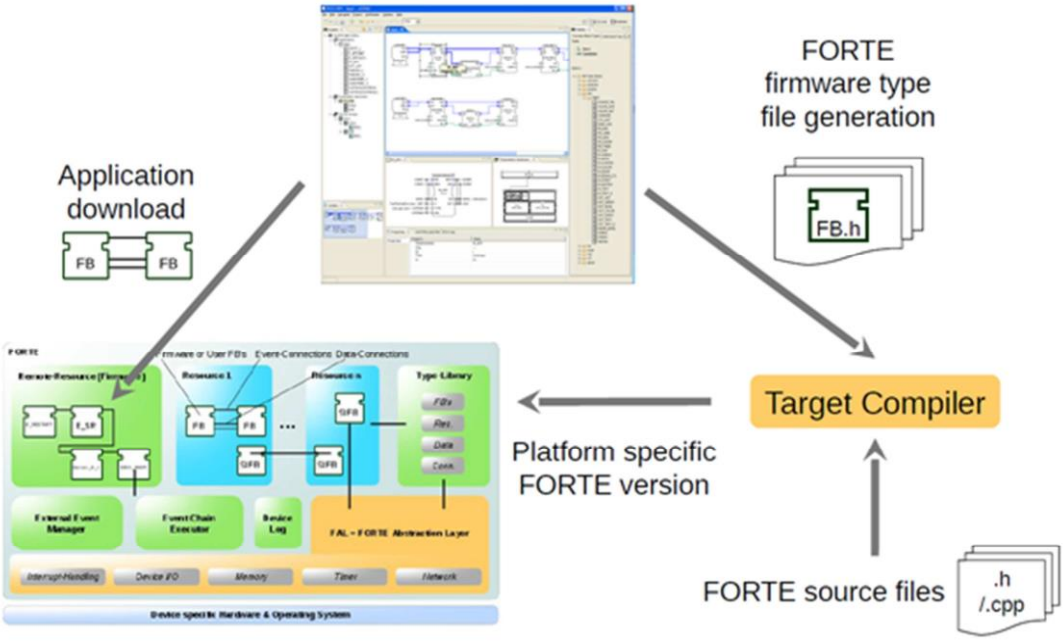

Figure 4: 4DIAC Toolchain

Additional information such as manuals, tutorials can be found at https://eclipse.org/4diac/.

4DIAC has already been adopted by both academic and industrial partners. Most projects running with the European CPSE-labs are investigating the integration of an OPC UA type of communication within 4DIAC.

MSEE Toolbox

The MSEE CPSM Toolbox is an Eclipse-based2 IDE for BSM/TIM modelling of Cyber-Physical Systems that derives from results of the FP7 MSEE research project3.

In this tool, the perspective on CPPS is that of business processes, which are modelled in a top-down fashion starting from objectives, assets, actors and decision grids and ending with an abstract specification of workflows and of applications/services. The outcome are BSM and TIM artefacts that may drive further steps of the CPPS engineering phase. In particular, the business-level framework defined by BSM artefacts (Extended Actigram and GRAI Grid models) is useful for engineering teams that use TIM-scoped CPPS design and simulation tools, while TIM artefacts (BPMN 2.0 and UML Class diagrams) may be consumed by software developers working at the TSM level. The following figure illustrates this architecture.

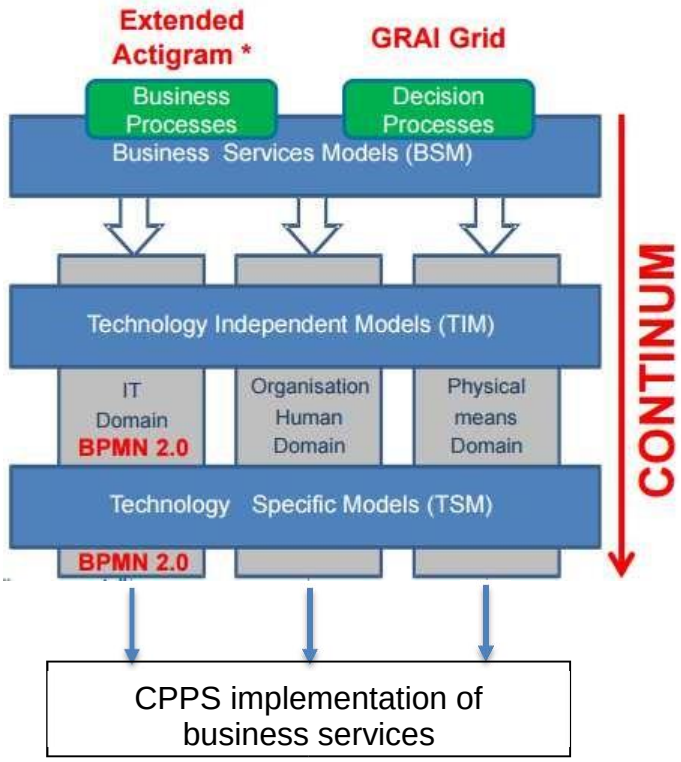

Figure 5: Architecture for modelling CPPS

According to the different architecture levels, we find the following modelling editors at each one of these levels:

[2] Built upon the Eclipse Platform – http://wiki.eclipse.org/Platform

[3] Manufacturing Service Ecosystem – http://www.msee-ip.eu/project-overview; the MSEE Service Lifecycle Management Modelling Toolbox is the asset on which the CPSM Toolbox is based - http://www.msee-ip.eu/admin/files/SLMToolBox/at_download/file

MDSEA Level	Goal	Modeling Langage	Editor
BSM	Describe service at high level	BSM Templates	Specific Development
	Describe simple business processes	Extended Actigram Star	Specific Development
	Describe decisional structures of the organization	Grai Grid	Specific Development
	Model the execution part of a decision structure	Grai Nets	Specific Development
	Capture data domain model	UML (Class Diagram)	Open Source Plugin (PAPYRUS)
TIM	Describe service at high level	TIM Templates	Specific Development
	Describe detailed business processes	BPMN2.0	Open Source Plugin (BPMN2.0 Modeler)
	Specify the IT artefacts	UML (Components ; Class Diagrams ; ...)	Open Source Plugin (PAPYRUS)

Figure 6: Modelling Editors

3.1.3. Proprietary components

UaModeler

The **UaModeler** from Unified Automation GmbH is a standalone desktop application that, according to the BEinCPPS Reference Architecture, belongs to the Virtual World domain: it is an engineering tool which supports developers in the design phase of Cyber-Physical Production Systems.

As its name implies, the UaModeler is a modeler that specifically targets OPC UA data models – i.e., the *address space* as per OPC UA jargon. In particular, it is an Integrated Development Environment (IDE) that allows users to design an application-specific address space using building blocks provided by the standard OPC UA ontology (classes, objects, relationships, etc.) and also to extend the generic ontology into a domain-specific one for reusing the same concepts in other address spaces.

The design process is as simple as building a hierarchical tree of nodes, and is entirely supported by visual tools, as depicted in the following example screenshot.

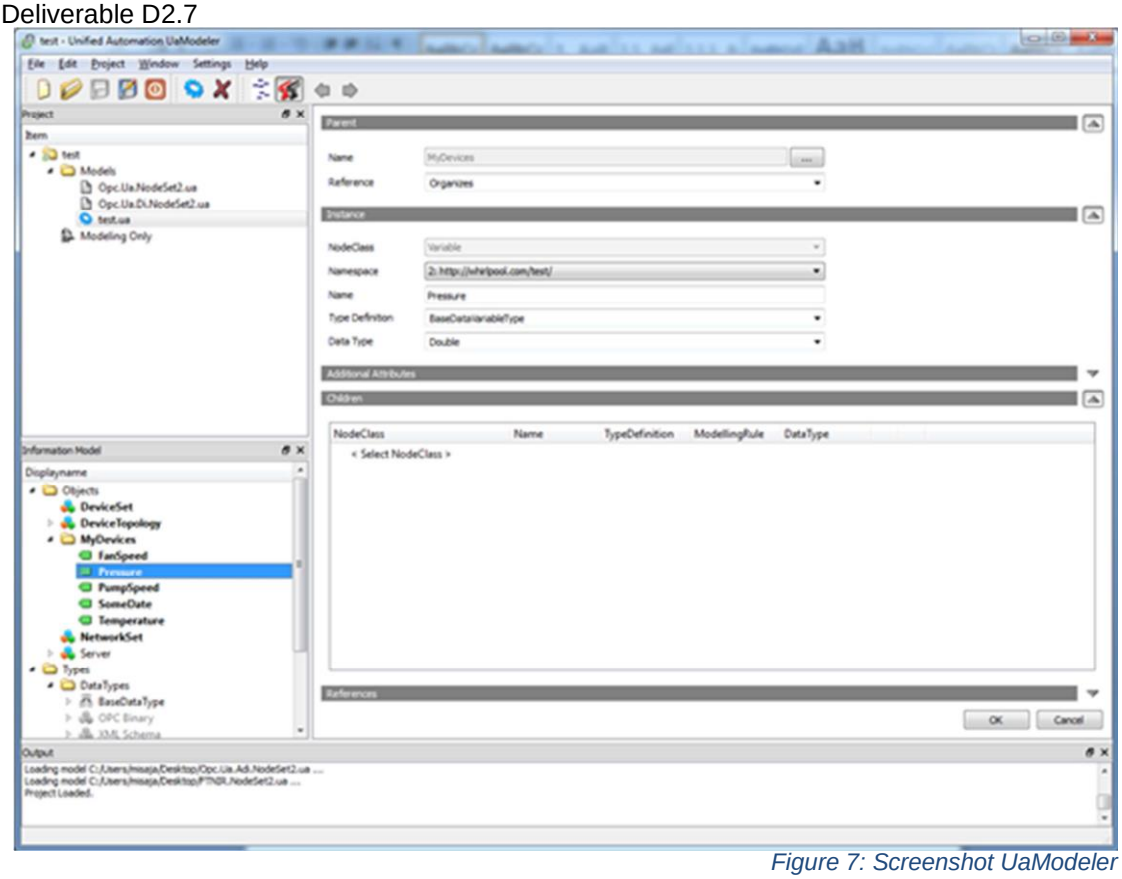

Figure 7: Screenshot UaModeler

The UaModeler is part of the Unified Automation SDK for the ANSI C, C++ and .NET programming languages: the main goal of these models is to be automatically converted into source code that can then be included into custom OPC UA servers and client applications. However, an extremely useful functionality of the IDE is its XML import/export capabilities, which is language- and SDK-independent. This means that an OPC UA address space and/or a domain-specific ontology can actually be designed for use with other tools that support the same simple formalism. The following code snippet provides a sample of it:

```
<UANodeSet xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:uax="
http://opcfoundation.org/UA/2008/02/Types.xsd" xmlns="
http://opcfoundation.org/UA/2011/03/UANodeSet.xsd" xmlns:s1="
http://whirlpool.com/test/Types.xsd" xmlns:xsd="http://www.w3.org/2001/XMLSchema">
    <NamespaceUris>
        <Uri>http://whirlpool.com/test/</Uri>
    </NamespaceUris>
    <Aliases>
        <Alias Alias="Double">i=11</Alias>
        <Alias Alias="DateTime">i=13</Alias>
        <Alias Alias="Organizes">i=35</Alias>
        <Alias Alias="HasTypeDefinition">i=40</Alias>
    </Aliases>
    <Extensions>
        <Extension>
            <ModelInfo Tool="UaModeler" Hash="JemCWlOeJIb7E8wqsLk2BQ==" Version="1.4.3"/>
        </Extension>
    </Extensions>
    <UAObject NodeId="ns=1;i=5002" BrowseName="1:MyDevices">
        <DisplayName>MyDevices</DisplayName>
        <References>
            <Reference ReferenceType="Organizes">ns=1;i=6002</Reference>
            <Reference ReferenceType="HasTypeDefinition">i=61</Reference>
            <Reference ReferenceType="Organizes" IsForward="false">i=85</Reference>
            <Reference ReferenceType="Organizes">ns=1;i=6005</Reference>
            <Reference ReferenceType="Organizes">ns=1;i=6001</Reference>
            <Reference ReferenceType="Organizes">ns=1;i=6003</Reference>
            <Reference ReferenceType="Organizes">ns=1;i=6004</Reference>
        </References>
    </UAObject>
    <UAVariable DataType="Double" NodeId="ns=1;i=6002" BrowseName="1:FanSpeed"
    UserAccessLevel="3" AccessLevel="3">
        <DisplayName>FanSpeed</DisplayName>
        <References>
            <Reference ReferenceType="HasTypeDefinition">i=63</Reference>
            <Reference ReferenceType="Organizes" IsForward="false">ns=1;i=5002</Reference>
        </References>
        <Value>
            <uax:Double>0</uax:Double>
        </Value>
    </UAVariable>
```

Figure 8: Code snippet UaModeler

In the scope of the BEinCPPS project, this feature is used for the definition of data models of OPC UA applications that are based on the NodeOPCUA[2] framework. This is an open source OPC UA stack for NodeJS[3]environments. Its server runtime can actually initialize an in-memory data model from a UaModeler XML export, greatly simplifying the development process.

The UaModeler is a closed source, commercial software. The product can be freely downloaded from the Unified Automation site: https://www.unified-automation.com/downloads/opc-ua-development.html. A commercial license for this tool is included in every purchased SDK package, and a specific licence can also be bought separately. However, the evaluation version can still be used without any license, with an XML export limit fixed to 10 nodes.

Documentation is included in the product as an online help.

Time-Sensitive Networking (TSN)

Ethernet technology has proven incredibly successful and is a near ubiquitous method of communication in the IT world. It is a very well standardized and open technology that is easily accessible to everyone, providing a wide range of bandwidth and physical layer options, and has significant support in a diverse range of application

[2] http://node-opcua.github.io/

[3] https://nodejs.org/en/

areas. Up until now there has been no real-time support in IEEE standardized Ethernet, leading to a number of proprietary modifications of Ethernet being used in industrial and transportation systems where real-time communication is a critical requirement. These solutions have typically been developed for specific tasks or domains, e.g. Profinet, EtherCAT and Ethernet/IP which compete for recognition in industrial automation. While these protocols perform their specialized tasks capably, they have limits when it comes to combining with standard (classical) Ethernet networks and devices. The scalability of adapted Ethernet solutions for different industries is also limited as each is tailored for a specific application area.
For this reason, the IEEE Time-Sensitive Networking task group has been working since 2012 on standardizing real-time functionality in Ethernet. TSN (Time-Sensitive Networking) is the set of IEEE 802 Ethernet sub-standards that are defined by the IEEE TSN task group. The new standards describe several mechanisms for improved or even guaranteed real-time delivery of Ethernet traffic. Most prominently, TSN defines the first IEEE standard for time-triggered message forwarding in a switched Ethernet network, and therefore fully deterministic real-time communication within the 802 suite of standards. Figure 9 depicts the level at which TSN is located in the communication model.

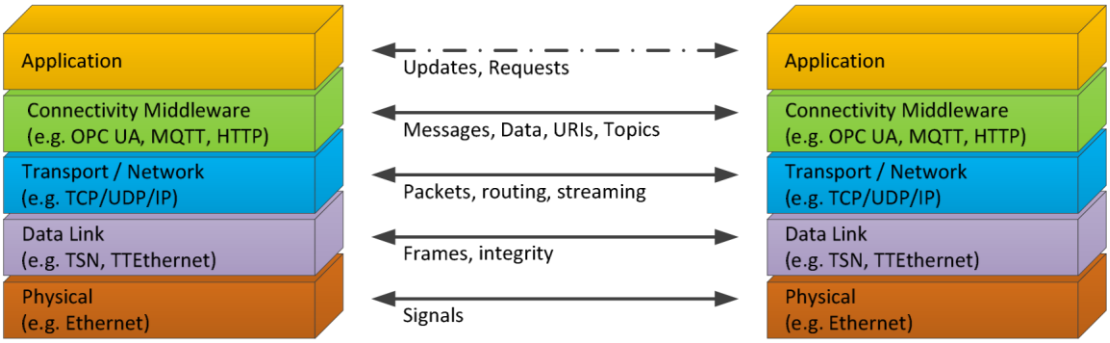

Figure 9: OSI abstraction layers

TSN achieves deterministic real-time communication over Ethernet by using global time and a schedule which is created for message paths across multiple network components. By defining queues which transmit their messages based on a time schedule, TSN ensures a bounded maximum latency for scheduled traffic through switched networks. In control applications with strict deterministic requirements, such as those found in automotive and industrial domains, TSN offers a way to send timecritical traffic over a standard Ethernet infrastructure. This enables the convergence of all traffic classes and multiple applications in one network. More information regarding manuals and deployment will be provided by TTTech.

3.2. Foreground components

This section describes the components that will be developed within the BEinCPPS specific context. These components are also divided into open source and proprietary components.

3.2.1. Open source components

4DIAC over TSN

Together with partner TTT, fortiss will work on providing an extension to 4DIAC which allows communication via Time Sensitive Networking (TSN) enabled switches

from TTT. This will make it possible to design IEC 61499 compliant PLCs benefitting from Guarantee of Service.
More information is provided in Factsheet #1.

Wireless Sensor Networks

The purpose of the wireless sensor network delivered as hardware/software part of the Smart Systems platform is to provide wireless communication capabilities to sensors or non-critical actuators (based on the reference architecture and protocol stack developed in the ARTEMIS project DEWI – "Dependable Embedded Wireless Infrastructure").
The TSCH mechanism provided by the IEEE 802.15.4e standard for WSN is expected to provide better reliability and bandwidth for wireless communication compared to its base standard (IEEE 802.15.4). To this state of the art wireless communications protocol stack, tools for smart network planning are also being developed and deployed, giving the possibility of optimizing scheduling for time slotted mesh networks which provide near real-time and robustness for hard environment features. This component is based on compatible hardware and developed under open source licensing.
More information is provided in Factsheet #2.

3.2.2. Proprietary components

TSN for periodic Real-Time OPC-UA Pub/Sub

In a first stage, partner TTTech will integrate OPC UA and TSN communication to provide soft real-time communication, thereby enabling a general communication network from the ERP system down to the machine level.

OPC UA is an open standard with a wide and quickly growing eco-system. It supports use cases for solutions like cloud-to-machine or cloud-to-factory. It offers all of the necessary services today, like e.g. encryption and security, browsing and services discovery, data logging and historian functions. TTTech is active in the standardization of an extension of the standard to add a notion of time to the data exchanged and to facilitate the periodic exchange of messages in (near-) real-time in the form of the publish/subscribe paradigm. In addition, with OPC-UA Pub/Sub utilizing TSN communication, a unified network for field level real-time and non-real time communication based on the OPC-UA model can be provided.
An extensive description of real-time OPC UA Pub/Sub with TSN is provided in the fact sheet #3 that can be found in the Appendix.

BEinCPPS µCEP

The BEinCPPS µCEP will enable complex processing on the edge of the networking, opening the possibilities for realizing Fog Computing infrastructure.
It represents a new generation of devices, like intelligent edge gateways, which are providing enterprises with the option to address computing challenges by performing critical data analytics close to endpoints at the edge of the network. They can aggregate different types of sensor data and normalize them into standard IP traffic that is well understood by IT.

In addition to unifying fragmented sensor data, an intelligent edge gateway has the processing capacity to perform additional analytics in real or new real-time to make data-driven decisions as close to the data generation as possible.
Performing analytics on the gateways helps reduce network bandwidth cost because only meaningful information needs to be sent to the next tier, whether it is another gateway, the datacentre, or cloud. Moreover, µCEP can communicate with the analytics modules placed on the server side and bring the global context close to the edge, by opening new possibilities for dynamic monitoring/processing on the edge. More information regarding the BEinCPPS µCEP van be found in the Factsheet #4 in the Appendix.

3.3. Guidelines for selection of components

Time-Sensitive Networking

Industrial applications such as machine control, robotics, power generation, process control and transportation all required real-time communication to perform safely and securely. To ensure that this critical requirements is met, industrial systems have typically either implemented modified Ethernet variants or dedicated standard Ethernet networking running in parallel. Now, industrial systems are expanding out from small closed networks to an industrial Internet of Things, where reliable, converged, remote, secure access to all network components is needed. Limited Ethernet access will no longer suffice for customers wishing to incorporate IoT concepts into their industrial systems to increase productivity, increase up-time or reduce maintenance. TSN supports both industrial control and IoT connectivity needs, enabling industrial real-time systems to benefit from techniques such as remote system management and maintenance, centralized data analytics and machine to machine coordination.
In general, TSN technology extends the functionality of standard Ethernet to now ensure that:

- Message latency is guaranteed through switched networks
- Critical and non-critical traffic can be converged in one network without risk of impact on the delivery of the critical traffic by collisions with the noncritical traffic
- Higher layer protocols can share the network infrastructure with real-time control traffic
- Components can be added to real-time control systems without network or equipment alterations
- Network faults can be diagnosed and repaired faster because of more precise information on their source

TSN has gathered the attention of major players from all sides of the industry. Companies such as Cisco, GE, National Instruments and TTTech are supporting TSN as a networking platform for the Industrial Internet of Things. They are all members of the Industrial Internet Consortium(www.industrtialinternetconsortium.org) , which aims to implement technologies in real-world applications, and is setting up a test bed for TSN in order to further define and develop the reference architecture and frameworks necessary for interoperability.

4DIAC

Within the RT context and especially for the field of manufacturing on its way to be digitized, a main aspect to be tackled is how to make platform architectures flexible

and adaptable. Commonly, the lower level of manufacturing systems is represented by the control applications. Control applications are built from tiny devices referred as programmable logic controllers (PLCs). PLCs are mostly proprietary to classic supplies such as Siemens. This is a barrier to innovation and to overcome it, we encourage the integration of open source platform such as 4DIAC, a framework for distributed industrial automation and control. The standard behind the platform, IEC 61499, improves and extends IEC 61131, the reference for most proprietary PLCs. The most important features of IEC 61499 is its support to the development, the deployment and the execution of *distributed* controllers.

4DIAC has already been used in several projects. As an illustration, we mention three success stories:

- The Austrian private research company PROFACTOR has used it for an application called "grasp in the box". This application realizes grasping of unordered objects from a box by a buckling arm robot. Within this application, 4DIAC coordinates up to 6 laser scanner, 3D image processing, automatic collision free path planning and interaction with the robot control. The application contains between 1500 and 1700 function blocks and processes 1Mbit of data per second.
- The AIT Energy Department used 4DIAC in an energy supply application to build a smart gird laboratory and simulates the main situation with solar inverters (65kW). The experiment includes a standard compliant implementation of intelligent electronic devices in active power distribution networks (i.e. smart grids) and its validation. Within this application, 4DIAC collects the data generated by about 1500 digital and 700 analogue I/Os and transfers them to SCADA-BR through Powerlink and Modbus respectively. It integrates the IEC 61850 standard for communication networks and systems for power utility automation.
- An Australian company NOJA Power signalled as well the adoption of 4DIAC within their Smart Grid Automation (SGA) software.

Wireless Sensor Networks

Using wireless technologies opens possibilities to new communication architectures and applications in the factory and automation field, where alternatives to traditional field buses are being increasingly taken into consideration for connectivity and control of machines and devices in industrial environments. The need for robust communications in harsh environments led to the development of protocols and architectures of reference such as the ones proposed in the project DEWI. This component enables wireless robust near real-time connection to gathering and exchanging data on the shop floor.

The intrinsically random behaviour of a radio frequency channel as propagation medium for information is always prone to some restrictions such as delay and interferences. Nevertheless, the WSN component provided packs different tools and mechanisms such as frequency hopping, dynamic routing, and channel access scheduling optimization in order to provide the best wireless communication experience for industrial environments.

Despite this, the recommended application of the component is for non-critical applications, such as actuators with real-time requirements. The WSN is a good option for applications where the emphasis is on fast deployment and dismantling,

mobility, and testing. The WSN allows to extend the sensoring network to points of difficult access, or where the investment in wired infrastructure is too high.
Success cases can be found in the European project DEWI, with applications in automotive, rail and building scenarios.

BEinCPPS µCEP

The need for more analytics, control and greater insight on IoT system cannot be met by just connecting more sensors, endpoints and other devices to the Internet. It is imperative to take a holistic approach to creating an environment that provides a scalable, predictable, secure, and manageable solution. Intelligent gateways like µCEP can play a significant role in keeping the balance between expansion and security. Moreover, by pushing analytics to the edge of the network, µCEP is also helping organizations make real-time decisions close to the data and reduce data storage and transfer challenges by focusing on the most meaningful data.
µCEP satisfies the requirements for having affordable and standardized (not proprietary) infrastructure for creating intelligent gateways for open industry systems. It is based on the work on developing mobile (Android-based) gateways for IoT applications.

4. Conclusions

This deliverable describes the Smart Systems Platform federation developed so far and the upcoming developments for the platform within the BEinCPPS project. This deliverable provides the basis for the champions and the future partners from the upcoming call regarding the components from the Smart Systems Platform. The components described within the project are the following:

- Time-sensitive Networking supporting Real-time OPC UA
- 4DIAC-RTE (FORTE)
- BEinCPPS µCEP
- Wireless Sensor Networks

The document identified which of the components are provided as background knowledge to the BEinCPPS project and which components will be further extended or completely new developed (foreground knowledge) to the project. The foreground knowledge is elaborated by describing the components in factsheets (appended to this document in the Annexes).

The document described the background and the first version of the foreground knowledge that will be developed within the BEinCPPS project and will be made available for the partners of the first open call. A second version of this deliverable (Deliverable D2.8, which is due in Month 24), will provide the second and final version of the foreground knowledge based, among others, on the feedback from the industrial champions and from the new partners coming out of the open calls.

Appendix 1 – CPS Components State of the Art

State of the Art document with respect to CPS components (CPS_Hardware_SotA.pdf)

Appendix 2 – Factsheets

FactSheet #1 – 4DIAC over TSN
Factsheet #2 – Wireless Sensor Networks
Factsheet #3 – TSN for periodic Real-Time OPC UA Pub/Sub
Factsheet #4 – BEinCPPS µCEP

Innovation Action Project

HORIZON 2020 - EU.2.1.5. - Ref. 680633

D2.7 - Smart Systems Platforms Federation
Factsheet #1
Relevant for 4DIAC over TSN Component

Lead Author: FORTISS

With contributions from: -

Delivery Date: September 2019

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1. Short Description of the component

4DIAC (eclipse.org/4diac) is an open source project developed at fortiss. It is composed of the 4DIAC integrated development environment (4DIAC-IDE) and the 4DIAC runtime environment (4DIAC-RTE, FORTE):

- 4DIAC-IDE is an extensible, IEC 61499[1] compliant engineering environment for distributed control applications. The modelled applications can be downloaded to distributed field devices according the means defined by the IEC 61499 standard.
- FORTE is a small portable implementation of an IEC 61499 runtime environment targeting small embedded control devices (16/32 Bit), implemented in C++. FORTE provides a flexible communication infrastructure via so called communication layers.

IEC 61499 based systems follow an application centric design, which means that the application of the overall system is created at first. Each 4DIAC application is created by interconnecting the desired function blocks (FB) in terms of a function block network (FBN). As soon as the hardware structure is known it can be added to a project's system configuration and the already existing application can be distributed onto the available devices.

With over 15 years' experience in time-scheduled networking, TTTech has the knowledge to make available novel devices such as TSN[2] enabled switches which guarantee the convergence of controls, streaming and data traffic over standard Ethernet networks without affecting real-time performance or wasting bandwidth.

By month 24, fortiss and TTTech will provide an extension to the current 4DIAC communication layer. The extension is made possible by means of the technology TTTech provides. The goal is to bring real-time communication via TSN and OPC UA into 4DIAC. This will make it possible to ensure that the Guarantee of Service is satisfied at PLC level.

2. Summary of main functionalities

Real-time communication via TSN switches for OPC UA into 4DIAC

3. BeInCPPS specific developments

Under development, due in month 24.

1 For compatibility, 4DIAC supports all IEC 61131-3 edition 2 elementary data-types, structures, and arrays.

2 TSN comprises a set of IEEE 802 Ethernet standards which provide latency guarantees for critical traffic in open and converged networks.

4. HW/SW Prerequisite

- TSN enabled switches for OPC UA from TTTech
- 4DIAC
- boards, to be decided later: Raspberry Pies, Beaglebones, Lego Mindstorms ...

5. Installation Instructions

The instructions for installing 4DIAC are at eclipse.org/4diac For 4DIAC+switch: Under development, due in month 24.

6. User Manual

The documentation for 4DIAC is at eclipse.org/4diac/documentation/help.html

Several tutorials are at

https://www.youtube.com/channel/UCt0MlNo6Y7dXCZSDACXFi1g For

4DIAC+switch: Under development, due in month 24.

7. Developers' Guide

Several tutorials are at: https://www.youtube.com/channel/UCt0MlNo6Y7dXCZSDACXFi1g Under

development, due in month 24.

8. Examples

Some textual examples of 4DIAC projects can be found at eclipse.org/4diac/en_sys.php

Videos are at https://www.youtube.com/channel/UCt0MlNo6Y7dXCZSDACXFi1g

For 4DIAC+switch: Under development, due in month 24.

9. Licensing

Depends on TTTech.

Innovation Action Project

HORIZON 2020 - EU.2.1.5. - Ref. 680633

D2.7 - Smart Systems Platforms Federation
Factsheet #2
Relevant for Wireless Sensor Networks Component

Lead Author: ITI

Ref 680633

Deliverable characteristics

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1. Short Description of the component

The purpose of the Wireless sensor network delivered as hardware/software part of the Smart Systems platform is to provide wireless communication capabilities to sensors or noncritical actuators. This component requires compatible hardware selection. For this hardware the component will provide optimized firmware for robust wireless communications, as well as the software for updating and managing this firmware and network planning and scheduling tools.

2. Summary of main functionalities

The main functionalities of the released firmware for wireless sensor networks nodes can be summarized as:

- Send information gathered by the node (via attached sensor interfaces to the analogue or digital I/O of the node's board), through a wireless interface radio supporting IEEE802.15.4e standard.

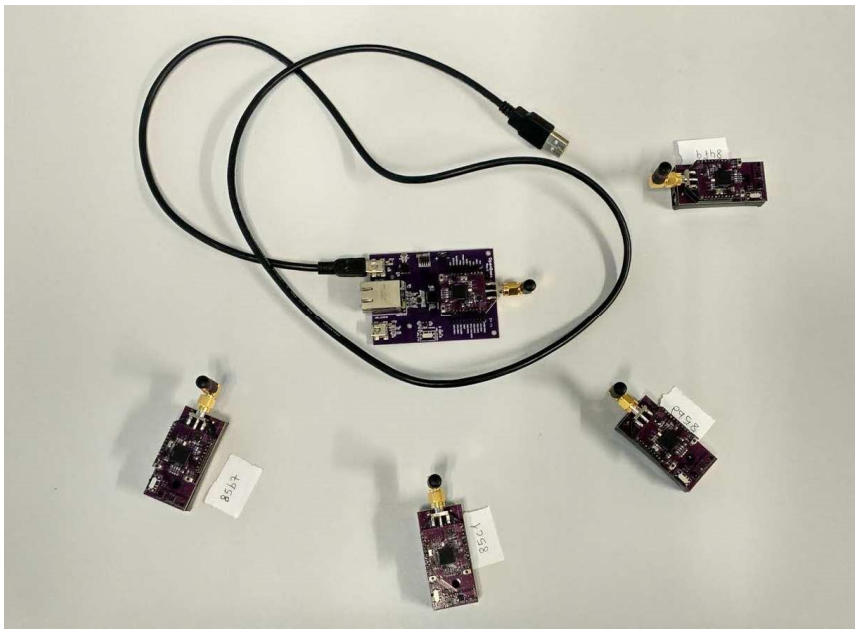


Figure 1 WSN Hardware for sending data wirelessly.

- Support dynamic routing (with RPL protocol) for reacting to topology or environment changes.

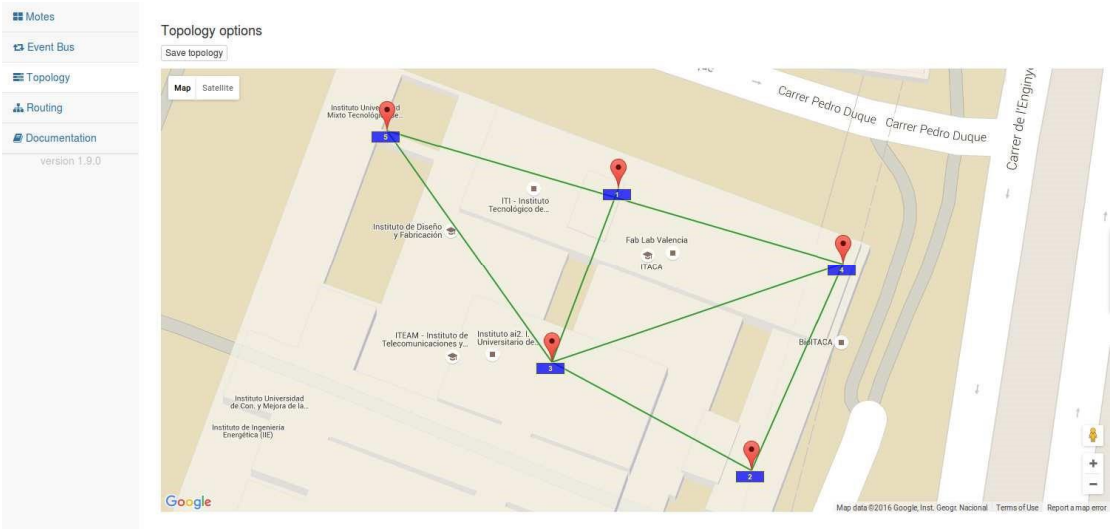
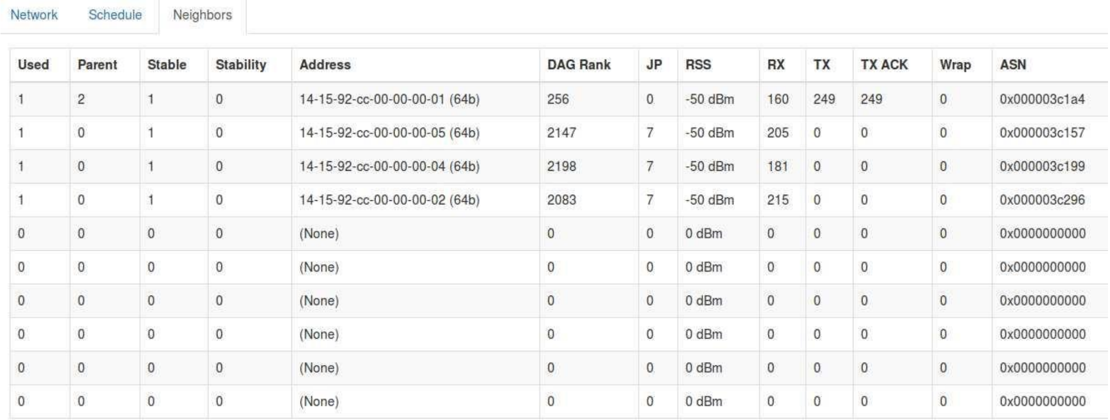


Figure 2 View of simulator and network visualizar software showing real topology

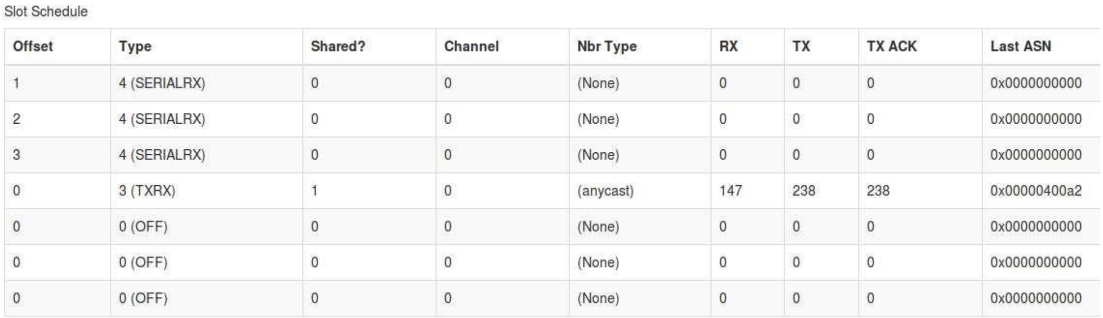
Figure 3 View of simulator and network visualizar software showing logical topology, reactive to changes.

- Support for time-slotted communication protocol with channel hopping features (time-frequency matrix, including multi-hop networks) for improved robust wireless communication and near real time applications.



Used	Parent	Stable	Stability	Address	DAG Rank	JP	RSS	RX	TX	TX ACK	Wrap	ASN
1	2	1	0	14-15-92-cc-00-00-00-01 (64b)	256	0	-50 dBm	160	249	249	0	0x000003c1a4
1	0	1	0	14-15-92-cc-00-00-00-05 (64b)	2147	7	-50 dBm	205	0	0	0	0x000003c157
1	0	1	0	14-15-92-cc-00-00-00-04 (64b)	2198	7	-50 dBm	181	0	0	0	0x000003c199
1	0	1	0	14-15-92-cc-00-00-00-02 (64b)	2083	7	-50 dBm	215	0	0	0	0x000003c296
0	0	0	0	(None)	0	0	0 dBm	0	0	0	0	0x0000000000
0	0	0	0	(None)	0	0	0 dBm	0	0	0	0	0x0000000000
0	0	0	0	(None)	0	0	0 dBm	0	0	0	0	0x0000000000
0	0	0	0	(None)	0	0	0 dBm	0	0	0	0	0x0000000000
0	0	0	0	(None)	0	0	0 dBm	0	0	0	0	0x0000000000
0	0	0	0	(None)	0	0	0 dBm	0	0	0	0	0x0000000000

Figure 4 View of a node neighbor table with statistics, shows no packets transmitted lost



Slot Schedule

Offset	Type	Shared?	Channel	Nbr Type	RX	TX	TX ACK	Last ASN
1	4 (SERIALRX)	0	0	(None)	0	0	0	0x0000000000
2	4 (SERIALRX)	0	0	(None)	0	0	0	0x0000000000
3	4 (SERIALRX)	0	0	(None)	0	0	0	0x0000000000
0	3 (TXRX)	1	0	(anycast)	147	238	238	0x00000400a2
0	0 (OFF)	0	0	(None)	0	0	0	0x0000000000
0	0 (OFF)	0	0	(None)	0	0	0	0x0000000000
0	0 (OFF)	0	0	(None)	0	0	0	0x0000000000

Figure 5 View of a simple scheduling for TSCH mode, implementing minimal 6TiSCH recommendations.

3. BEinCPPS specific developments

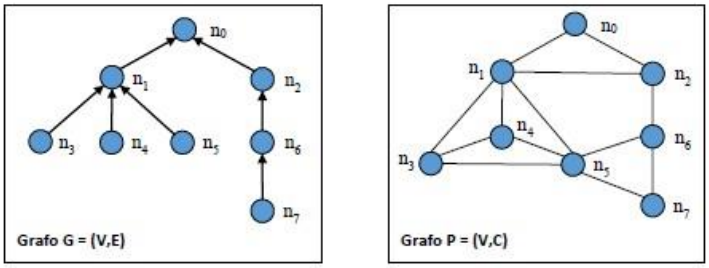
The TSCH mechanism provided by the IEEE 802.15.4e standard for WSN is expected to provide better reliability and bandwidth for wireless communication compared to its base standard (IEEE 802.15.4), because it uses multiple channels and hops between them in order to avoid getting trapped in noisy channels. It also helps to avoid poor link quality between two

nodes due to channel fading effects in a particular channel.

To evaluate this rather new standard technology, we first needed to have an implementation of the protocols stack. Unfortunately, at the start of the BEinCPPS project, the available implementation of the TSCH and upper layers like 6LoWPAN was rather limited. The most actual version of the firmware for WSN devices is implementing the minimal 6TiSCH recommendation, which enables nodes to communicate but in fact only takes the CSMA-Ca mechanism of the base standard and allocates it inside a time slot of the TSCH frame. Then, this works of the shelve but it only offers better performance in terms of channel noise, but nothing from the time slotted guaranteed traffic features.

The firmware and tools provided by the WSN module of the Smart Systems platform enables selected hardware to operate with the most up to date standards recommendations (IEE802.15.4e TSCH mode with minimal 6TiSCH), and also provides the tools (like simulator and schedule planner) and guide to plan and deploy a WSN with optimized scheduled communications.

Specifically, at time of release of this document, the planning tool supports the TASA (Traffic Aware Scheduling Algorithm) centralized schedule optimization algorithm (see figure 6), which output can also be tested with a provided simulator before real deployment. Further developments may include better integration of the tool with deployed firmware and extended optimization mechanisms support.



PLANIFICATION

SLOT 0 chOff=0 (tx=1,rx=0) chOff=1 (tx=6,rx=2) SLOT 1 chOff=0 (tx=2,rx=0) chOff=0 (tx=7,rx=6) chOff=1 (tx=3,rx=1) SLOT 2 chOff=0 (tx=1,rx=0) chOff=1 (tx=6,rx=2)

SLOT 3 chOff=0 (tx=2,rx=0) chOff=1 (tx=4,rx=1) SLOT 4 chOff=0 (tx=1,rx=0) SLOT 5 chOff=0 (tx=2,rx=0) chOff=1 (tx=5,rx=1) SLOT 6 chOff=0 (tx=1,rx=0)

TSCH with TASA = 7 slots

With TDMA = 13 slots

Algorithm 1 Traffic Aware Scheduling Algorithm (TASA)

```
procedure SCHEDULING(G, P, q, Q, n_ch)      ▷ G: Graph
                                            ▷ P: PHY Connectivity Graph
                                            ▷ q: q_i(k) vector, Q: Q_i(k) vector,
                                            ▷ n_ch: number of available channels,
    k ← 0                                   ▷ slot initial value
    pattern ← [ ]                           ▷ time/frequency pattern initial value
    while q_0(k) ≠ Q̄ do                     ▷ The procedure is run until a
                                            ▷ pattern that allows to delivery to
                                            ▷ the PAN Coordinator all the packets
                                            ▷ generated in one slotframe, is built
        DCFL(k) ← MATCHING(G, q, Q, n_0, k)
        I(k) ← FINDINTERFGRAPH(DCFL(k), P)
                                            ▷ Building the Interference
                                            ▷ Conflict graph for DCFL(k)
        colored ← COLORING(I(k), Q)
        selected ← [ ]
        for n ← 1 to n_ch do
            selected ← GETFIRST(colored)
        end for
        UPDATE(q, Q, selected)              ▷ Updating q,Q
                                            ▷ according to links scheduled at k
        pattern ← pattern + [(k, selected)]
        k ← k + 1
    end while
    return pattern                          ▷ returning time/frequency pattern
end procedure
```

Figure 6 Example of network scheduling optimization, showing physical and logical topology, TASA pseudocode, and the output log of the planner implementation. schedule

4. HW/SW Prerequisite

There are certain prerequisites needed to deploy the WSN component in a selected use case:

- Compatible hardware with radio support for standard IEEE802.15.4e and OpenWSN SO. (See short list below).
  - Zolertia Z1 (http://zolertia.io/product/hardware/z1-platform)
  - Zolertia RE-Mote (http://zolertia.io/product/hardware/re-mote)
  - OpenMote CC2538 (http://www.openmote.com/shop/openmotecc2538.html)
  - CM5000 – TelosB (http://www.advanticsys.com/shop/mtmcm5000msp-p14.html?language=en) • Gateway device that enables WSN nodes to connect with external LANs/Internet. Typically, and embedded PC with an IEEE802.15.4e interface, which acts as WSN root node, and another network interface (wired or wireless). Linux based OS recommended.
- Batteries and recharging infrastructure (ESB cables, battery recharger, etc.).
- Computer with USB slots available and Linux OS for programming and updating node's software. It can be the same device used as gateway.
- C programming language compiler.
- Node.js installed.

5. Installation Instructions

Instruction on how to install and run the OpenWSN software required for programming and developing the WSN is available at:

- https://openwsn.atlassian.net/wiki/display/OW/Get+Started

This also can be done in any Linux SO, downloading and running the install script provided in the zip file below (section 6 Manuals), which also contains manuals, guides and other binaries that enable more features and help a rapid WSN deployment.

For installing Node.js, please visit:

- https://nodejs.org/en/download/package-manager/

6. User Manual

The manual for updating the nodes firmware and starting the WSN operation can be found at:

- https://dbox.iti.upv.es/oc/index.php/s/RwiUnhMH835brI3

The scripts for installing and running the examples assume all files have been installed in the "home" folder.

For enabling internet access (in case IPv6 is not available on remote host) to the WSN deployed, follow instructions at:

- https://openwsn.atlassian.net/wiki/display/OW/Internet+Integration

7. Developers' Guide

The manual for developers in order to make changes to node firmware and select alternative application layers, operating modes, sensor interfaces, etc., can be found in the same folder as the user manuals, at:

- https://dbox.iti.upv.es/oc/index.php/s/RwiUnhMH835brI3

8. Licensing

The OpenWSN software used as base by this component has the following licensing:

"Copyright (c) 2010-2014, Regents of the University of California.

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Redistribution and use in source and binary forms, with or without modification,

are permitted provided that the following conditions are met:

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Innovation Action Project

HORIZON 2020 - EU.2.1.5. - Ref. 680633

D2.7 - Smart Systems Platforms Federation
Factsheet #3
Relevant for Real-Time OPC UA over TSN Component

Lead Author: TTTech

With contributions from: TTTech

Delivery Date: September 2016

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1. Short Description of the component

1.1 Time-Sensitive Networking (TSN)

Ethernet technology has proven to be incredibly successful is a near ubiquitous method of communication in the IT world. It is a very well standardized and open technology that is easily accessible to everyone, provides a wide range of bandwidth and physical layer options, and has significant support in a diverse range of application areas. Until now, there has been no real-time support in IEEE standardized Ethernet, leading to a number of proprietary modifications of Ethernet being used in industrial systems where real-time communication is a critical requirement. These solutions have typically been developed for specific tasks or domains, e.g. PROFINET, EtherCAT and Ethernet/IP which compete for recognition in industrial automation. While these protocols perform their specialized task capably, they have limits when it comes to combining with standard (classical) Ethernet and devices. The scalability of adapted Ethernet solutions for different industries is also limited as each is tailored for a specific application area.

TTTech is working together with the IEEE TSN Working Group to create an open global standard to solve this challenge. Time-Sensitive Networking (TSN) is the set of IEEE 802 Ethernet sub-standards that describe several mechanisms for improved or even guaranteed real-time delivery of Ethernet traffic. Most prominently, TSN defines the first IEEE standard for time-triggered message forwarding in a switched Ethernet network, and therefore fully deterministic real-time communication within the 802 suite of standards. TTTech has developed a first reference implementation of TSN capable switches for the industrial domain[4]. TSN achieves deterministic real-time communication over Ethernet by using global time and a schedule which is created for message paths across multiple network components. By defining queues which transmit their messages based on a time schedule, TSN ensures a bounded maximum latency for scheduled traffic through switched networks. In control applications with strict deterministic requirements, such as those found in automotive and industrial domains, TSN offers a way to send time-critical traffic over a standard Ethernet infrastructure. This enables the convergence of all traffic classes and multiple applications in one network.

1.2 OPC UA Pub/Sub

OPC UA is a a cross-platform service-oriented architecture and data exchange technology widely used in the industry[5]. Traditionally, OPC UA utilizes an event-driven clientserver model which is not suitable for real-time communication or field level control.

OPC UA Publish/Subscribe (Pub/Sub) is an extension to the commonly-used OPC UA, which enables periodic communication and multicast data exchange between nodes. In order to utilize OPC UA Pub/Sub for periodic exchange of control data, a real-time communication mechanism is most suited to provide temporal predictability in the data exchange, which is provided by TSN.

In BEinCPPS, an OPC UA stack capable of communicating throuh Pub/Sub service utilizing TSN is provided. The OPC UA SDK is an SDK compatible with among other, embedded Linux that needs to be running on the endpoints in the network.

Besides the sensor or cloud connectivity in a many-to-one scenario, the new connectionless Pub/Sub communication reveals additional use applications. A local communication, between well-known participants like PLCs, often requires very frequent transmissions of small amount of data. However, this communication needs guaranteed response times, known as deterministic real-time. Therefore, Pub/Sub communication will be

[4] https://www.tttech.com/technologies/deterministic-ethernet/time-sensitive-networking/
[5] https://opcfoundation.org/about/opc-technologies/opc-ua/

combined with the Ethernet extensions for TSN. Pub/Sub communication is organized between OPC UA Pub/Sub servers and clients and works as follows. Pub/Sub server announces available data signals in a form of data sets, to which client(s) can subscribe. One Pub/Sub client(s) are subscribed to particular data sets, the server published them to the network, using TSN multicast TSN dataflows.

In the network, switches bind the TSN dataflows to the synchronized (and coordinated) schedules to guarantee the network-wide real-time data transport. In other words, once the OPC UA Pub/Sub is sent using prioritized TSN traffic, it will be delivered in a deterministic manner: with guaranteed latency and jitter. Such dataflows cannot be disturbed by Best Effort (BE) or even TSN traffic (with lower priority).

2. Summary of main functionalities

The main functionalities of the integration of real-time OPC UA pub/sub in TSN are:

- Pub/sub combined with TSN offers new application fields

The general pub/sub approach applied by OPC UA combined with the capability of TSN to merge all traffic classes and multiple applications over one network makes it possible for manufacturing industry to become vendor independent. Sensors, actuators and machine control from various vendors can be easily merged and interconnected without having to take care of interoperability adjustments. OPC UA pub/sub provides a generic data exchange concept and the usage of TSN provides a communication network that support non-critical as well as real-time communication, paving the way for new applications fields.

- Integrate real-time world with IT world

OPC UA pub/sub over TSN builds bridges between the IP-based IT world and protocols for real-time requirements like EtherCAT, ProfiNET or EtherNet/IP. OPC UA over TSN is the ideal solution for all industrial applications that are located above the machine level with real-time requirements. This includes applications like e.g., line synchronisation, connections to SCADA systems up to control applications.

3. BEinCPPS specific developments

The merging of OPC UA pub/sub with the Time-Sensitive Networking (TSN) is more than just adding the two parts together. Currently, the available OPC UA pub/sub stacks are not TSN aware and therefore cannot make use of the substantial advantages of TSN (e.g. synchronisation, convergence, robust delivery, etc.). To solve this, modifications of the applied OPC UA stacks are mandatory.

To integrate OPC UA with TSN, the OPC UA Pub/Sub stack is connected to TSN using the User Datagram Protocol (UDP), as depicted in Figure 1. The advantage of connecting over UDP is that communication is not only able to SCADA systems, but also down to the device or down to the controller, and a fully distributed control system can be developed based on OPC UA. For traditional OPC UA, there is a client-server architecture, where on part of the server provides the data and another part is doing the acquisition, which is performed always in a fixed point-to-point relation. With Pub/Sub you'll get the functionality to define a fixed time-window where data can be exchanged, using multi-point connection via UDP. This gives one a communication frame which is addressed to many other PLCs, not only to one. In the current version of OPC UA over TSN, soft real-time communication will be supported, enabling communication within certain limited timeframes. Real-time communication here doesn't mean performance in terms of being first of fast, it means being deterministic, meaning having a time-window in which the communication has to be delivered.

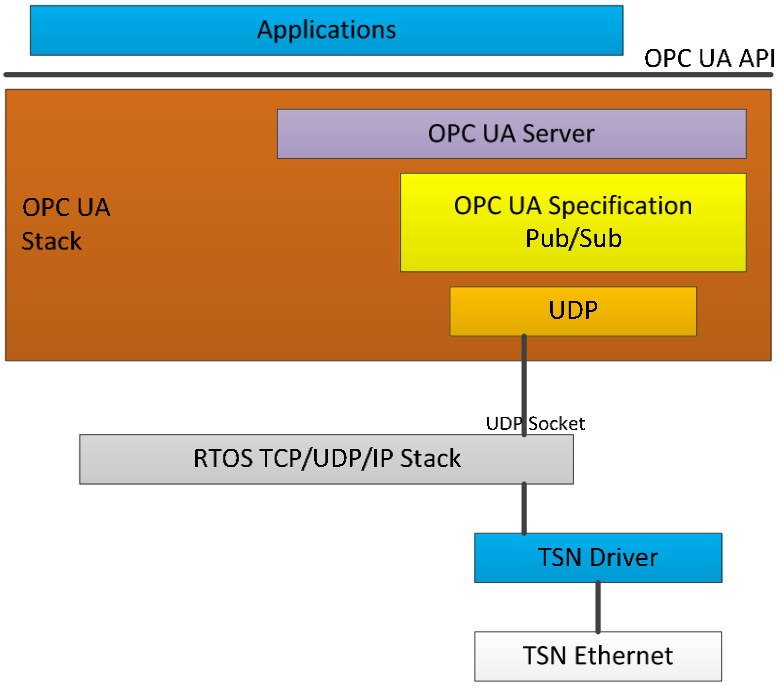

Figure 1: Real-time OPC UA Pub/Sub via UDP over TSN

For the second version of Real-time OPC UA Pub/Sub over TSN, the main focus is on the improvement of the performance to support hard real-time communication. In the first version, provided at time of release of this document, soft real-time provides communication round trip delay of around 15msec, without a fixed guarantee of delivery, resulting in a potential loss of messages.

With hard real-time delivery, the goal is at a lower round trip delay aiming at a time of well below 1msec without jitter and with guaranteed delivery of the data to enable. precise machine-to-machine communication, e.g. coordination between a robot and the tool mounted on it.

4. HW/SW Prerequisite

The following hard- and software prerequisites are needed to deploy the Real-Time OPC UA over TSN component in selected use cases.

Hardware

- Time-sensitive Networking (TSN) Switch (https://www.tttech.com/products/industrial/switches/iot-switches/de-switch-akro-60tsn/)
- TSN end nodes, including with a network interface card. This enables real-time communication over dual redundant synchronous network channels for seamless redundancy management in high-availability real-time networks. It supports three different traffic classes on the network: ○ Best-effort Ethernet traffic ○ Streaming (rate-constrained) traffic
    - Synchronous (time-triggered) traffic with hard real-time guarantee and transport-delay jitter in sub-microsecond range for mission-critical and safety-critical real-time applications.

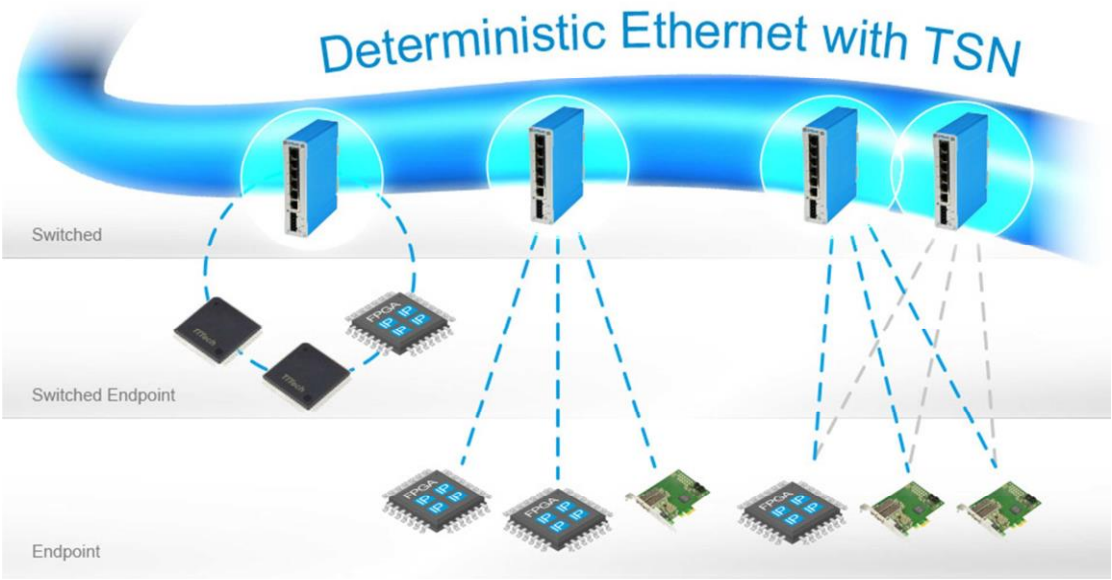

Figure 2: Hardware for Deterministic Ethernet with TSN

Software level

- RTOS (e.g. Linux Ubuntu 14.04) with RT patch
- RT OPC UA Stack (Binary version is provided by a leading supplier of OPC UA engaged in a development partnership with TTTech)

5. Installation Instructions

Installation instructions will be provided by TTTech.

6. User Manual

The user manual for the TSN-enabled switches together with the (real-time) OPC UA Pub/Sub implementation will be provided by TTTech with the hardware.

7. Developers' Guide

Developers' guide will be provided by TTTech.

8. Examples

An example of a TSN testbed can be found under:
https://www.tttech.com/news-events/press-corner/details/tttech-joins-tsn-testbed/

9. Licensing

Proprietary Licensing by TTTech.

Innovation Action Project

HORIZON 2020 - EU.2.1.5. - Ref. 680633

D2.7 - Smart Systems Platforms Federation
Factsheet #4
Relevant for µCEP Component

Lead Author: Nissatech

With contributions from: -

Delivery Date: September 2016

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1. Short Description of the component

The task of µCEP is to pre-process events in close proximity to their source, avoiding network latency and thus enabling a first level of true real-time control. Additionally, this approach protects the privacy of data since the manufacturing data will be processed locally

2. Summary of main functionalities

The main functionalities of the BEinCPPS µCEP are:

- manage patterns (create, edit, delete)
- manage input streams (select inputs for patterns, connect them)
- enable connection to input streams (Bluetooth, …)
- define output events and actions

Extended functionalities that will be provided are:

- store events locally
- connect to broker
- upload events to server
- publish patterns to server
- import patterns/events from server

QoS:

- ensure privacy/security of data/services

3. BeInCPPS specific developments

The entire component is a specific development for the project

4. HW/SW Prerequisite

HW: Raspberry Pi 3* SW:

Java

A 1.2GHz 64-bit quad-core ARMv8 CPU 802.11n Wireless LAN Bluetooth 4.1 Bluetooth Low Energy (BLE) Like the Pi 2, it also has: 1GB RAM 4 USB (101KB)

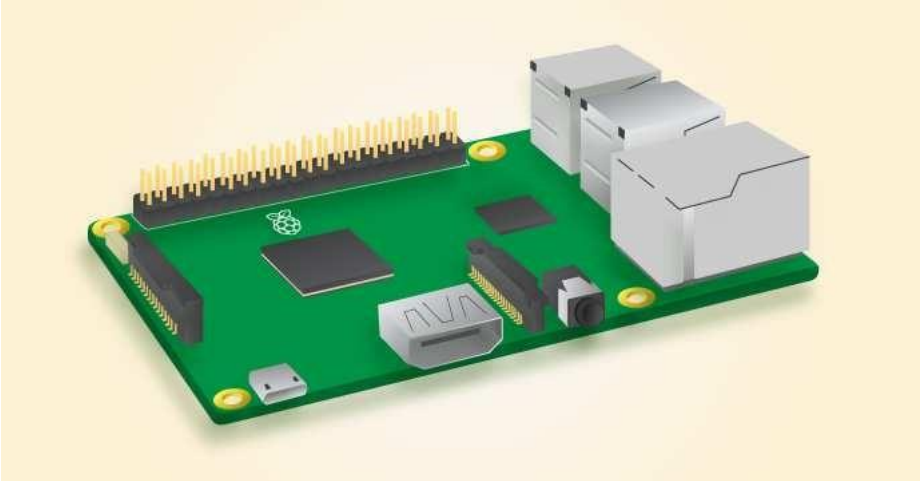

Figure 1: µCEP Hardware

5. Installation Instructions

Will be provided by NISSA.

6. User Manual

Will be provided by NISSA.

7. Developers' Guide

Will be provided by NISSA.

8. Examples

Will be provided by NISSA

9. Licensing

The licence will be decided on by NISSA as soon as the component is provided.

Innovation Action Project

HORIZON 2020 - EU.2.1.5. - Ref. 680633

D2.7 - Smart Systems Platforms Federation
ANNEX: CPS and embedded systems State of the Art

Lead Author: ITI

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1. Introduction

In few words Cyber-Physical Systems (CPS) refers to the integration of computation, networking and physical processes in the same system. CPS are composed by embedded computers and communication networks that monitor and control the physical processes with feedback loops where these physical processes affect computations and vice-versa ***[cyberphysicalsystems]***. Embedded computation is the core part of system.

During the design of a CPS we have to take into account the different design practices between the various engineering disciplines that are involved in, from software design to mechanical engineering. Designing and deploying a cyber physical production system can be done based on the 5C architecture (connection, conversion, cyber, cognition, and configuration). In the "Connection" level, devices can be designed to self-connect and selfsensing for its behaviour. In the "Conversion" level, data from self-connected devices and sensors are measuring the features of critical issues with self-aware capabilities, machines can use the self-aware information to self-predict its potential issues. In the "Cyber" level, each machine is creating its own "twin" by using these instrumented features and further characterize the machine health pattern based on a "Time-Machine" methodology. The established "twin" in the cyber space can perform self-compare for peer-to-peer performance for further synthesis. In the "Cognition" level, the outcomes of self-assessment and selfevaluation will be presented to users based on an "infographic" meaning to show the content and context of the potential issues. In the "Configuration" level, the machine or production system can be reconfigured based on the priority and risk criteria to achieve resilient performance ***[CPSWikipedia]***.

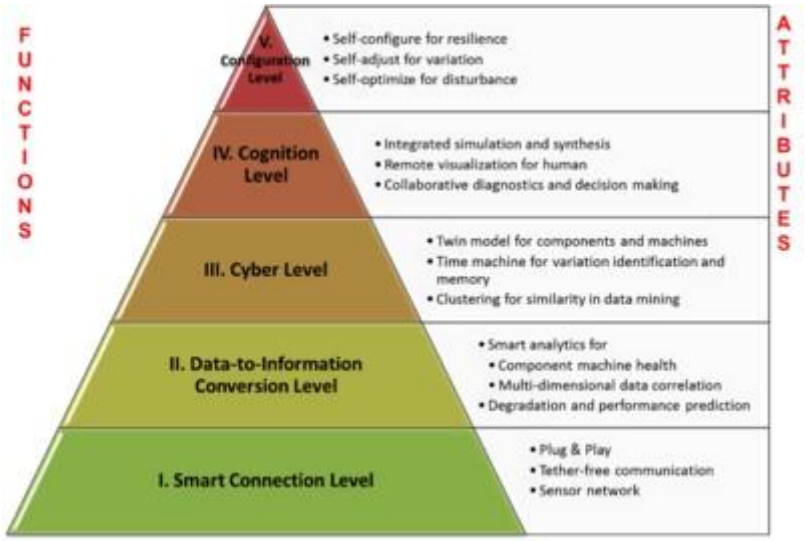


Figure 1. CPS architecture design

In this document we will describe and analyse some hardware and software related to the development of CPS, in particular referring to the design and development of embedded systems.

Embedded systems are particular computers designed to perform defined tasks usually with real time constraints (that is the main difference with personal computers that are designed to face with wide range of applications and needs). Embedded systems integrate a wide range of interfaces or peripherals inside the main board as communication interfaces, video interconnection, input/out pins. That allows to be mass-produced and therefore reduce the cost of the product. Embedded systems can range from portable devices as digital watches or MP3 players to large stationary installations like traffic lights, factory controllers or as it is usually integrated to control different parts of cars, avionics or factories.

Embedded systems computers are usually assembled with a small processor and memory size (due it only needs to do few tasks) providing few interfaces to interact with them. The software usually are written in low-level languages in order to optimize speed and efficiency of the algorithms, facing with the particular constraints of the systems: power consumption limits, small amount of memory or storage, etcetera.

Finally embedded systems can be characterized and classify by different properties. Nevertheless we can distinguish these systems in base a two main characteristics:

- Complexity: in which systems can be classified:
    - **Small Scale Embedded Systems**: in which there are not operating systems and they are based on simple programs running on basic microcontrollers.
    - **Medium Scale Embedded Systems**: in which programs are relatively complex and require from more powerful hardware. Usually run tiny operating systems.
    - **Complex Embedded Systems**: in which powerful hardware designs run big operating systems (as Linux based distributions) with complex programs.
- Property: in which systems are classified by the intellectual property of the hardware and software. They can be: ○ **Proprietary**. ○ **Open source**. ○ **Hybrid**.

2. Normatives

In order to develop products for the industry a lot of normatives, best practices and techniques should be followed by the manufacturers in order to assure the quality of the products. In general, embedded computers manufactures follow a set of common practices and guidelines that their products fulfil. Usually, devices for the industry are enclosed into hard design or rugged chassis in order to resist vibrations, shocks, falls and also to prevent the damage from dust particles, temperatures and air conditions from the environment. In the design of the device, a set of tests must be passed. It is usual that high percentages of electronic failures will occur in the first day of operation in the environment that is call as “infant mortality”. Also BIOS and software is tested with the leading products on the market. Some desirable characteristics for an industrial device are (based on average characteristics of products):

- **Temperature**: it should perform between temperatures below zero and above 50º C.
- **Shock in operation mode**: it should resist 15g peak acceleration with 11 msec duration.

- **Vibration in operation mode**: from -5 to 2000 Hz (.006" peak to peak displacement) and 1g of maximum acceleration.
- **Shock in non operating mode**: it should resist 30g peak acceleration, 11 msec duration.
- **Vibration in non operationg mode**: from -5 to 2000 Hz (.006" peak to peak displacement) 1g of maximum acceleration.

Moreover, if the device needs from rotation media as disk drives, they can reduce the tolerance values for the unit to shock and vibration. For this reason, diskless operating systems are desired.

The design must pay attention in provide the amount of power needed by the computer and peripherals without exceeding the limit of the established power consumption. Also it is important that devices be mechanically designed to be backward compatible with legacy products and components in order to maximise product lifetime, by following the industry standards. Modular design will be desirable to allow easy upgrading. Finally, software versions should be configured to be compatible with legacy versions.

In addition, there exist a lot of normatives, standards, design practices, guidelines, etcetera that affect to the design and development of embedded systems. These directives provide different codes, names, classifications, etcetera that ensures that a particular product fulfil different properties or attributes. Some of the most important ones are commented in next sections.

1.1. IP Code

IP Code, or the International Protection Marking (IEC 60529) are responsible to define and classify the rates for the protection and resistance of devices against intrusion, dust, accidental contact and water resistance of the mechanical chassis and electrical enclosures ***[iec]***. These code consists on the fixed word IP followed by a sequence of numbers/letters as:

- **solid particle protection**: X or 0-6.
- **liquid ingress protection**: 0-9.
- **mechanical impact resistance**: 0-9 *(no longer used)*.
- **other protections**: single letter.

The word X means that the value is not important or significant. One of the most common standards is the IP67 normative. Also IP69K developed by the German standard DIN 40050-9 extends the basic normative for rating high-pressure, high-temperature and wash-dow applications.

1.1. MIL-STD-810

The MIL-STD-810 normative from the Environmental Engineering Considerations and Laboratory Tests is used as United States Military Standard for providing tests for checking the limits of environmental conditions of the material ***[MIL-STD-810]***. These tests include:

- Test Method 500.5 Low Pressure (Altitude).

- Test Method 501.5 High Temperature. Test Method 502.5 Low Temperature. Test Method 503.5 Temperature Shock.
- Test Method 504.1 Contamination by Fluids.
- Test Method 505.5 Solar Radiation (Sunshine).
- Test Method 506.5 Rain.
- Test Method 507.5 Humidity.
- Test Method 508.6 Fungus.
- Test Method 509.5 Salt Fog.
- Test Method 510.5 Sand and Dust.
- Test Method 511.5 Explosive Atmosphere.
- Test Method 512.5 Immersion.
- Test Method 513.6 Acceleration.
- Test Method 514.6 Vibration.
- Test Method 515.6 Acoustic Noise.
- Test Method 516.6 Shock.
- Test Method 517.1 Pyroshock.
- Test Method 518.1 Acidic Atmosphere.
- Test Method 519.6 Gunfire Shock.
- Test Method 520.3 Temperature, Humidity, Vibration, and Altitude.
- Test Method 521.3 Icing/Freezing Rain.
- Test Method 522.1 Ballistic Shock.
- Test Method 523.3 Vibro-Acoustic/Temperature.
- Test Method 524 Freeze / Thaw.
- Test Method 525 Time Waveform Replication.
- Test Method 526 Rail Impact.
- Test Method 527 Multi-Exciter.
- Test Method 528 Mechanical Vibrations of Shipboard Equipment.

MIL-STD-810 is a flexible standard that allows users to tailor test methods to fit the application. This has the result that vendor's can claim the words "…compliance to MILSTD-810…", altought no commercial organization or agency certifies compliance. For this reason, commercial vendors can create the test methods or approaches to fit their own purpouses due some of the tests can be expensive to be performed.

1.1. MIL-STD-461

The MIL-STD-461 normative ***[MIL-STD-461]*** is a standard from the United States Military used to described how to test equipment for electromagnetic compatibility. It is important to note that if a device complies with this normative, then it is certain to comply with the FCC Part 15 and EMC standards of other countries.

1.1. MIL-S-901

The MIL-S-901 normative ***[MIL-S-901]*** is a military specification for High Impact mechanical shock which applies to equipment that could be mount on ships. It defines a set of levels:

- Grade A: that are applied to devices that are essential to the safety and combat capability of the sip.

- Grade B: that are applied to devices whose operation is not essential to the safety and combat capability of the ship but which could become a hazard to the personnel.

1.2. IEEE 1613

The IEEE-1613 standard ***[IEEE1613]*** defines the environmental and testing requirements for communications networking devices used in electric power substations installations.

1.1. Intrinsic safety

Intrinsic Safety (IS) ***[IntrinsicSafety]*** defines protection techniques for the safe operation of electrical equipment in hazardous areas by means of limitng the energy, electrical and thermal and the possibilities and availability of ignition. It is used in signal and control circuits that can operate with low currents and voltages. In fact, is the application of the inherement safety into instrumentation design and implementation. Nevertheless, high-power circuits cannot use these definition for protection.

1.1. TEMPEST

TEMPEST ***[TEMPEST]*** is a National Security Agency specification and certificaction of the NATO that refers to the possibility of spying on information systems through unintentional radio o electrical signals, sound or vibrations. These protection is done providing guides for distance, shielding, filtering and etecetera to the devices including distance from walls, amount of shielding in equipment and separation of wires.

1.1. ATEX

ATEX ***[ATEX]*** is a directive consisting in the inclusing of two EU directives that describe which type of equipment is allowed to peform inside an explosive atmosphere. ATEX derives its name from the French title of the 94/9/EC directive: *Appareils destinés à être utilisés en ATmosphères EXplosibles*.

1.1. EN-62262 / IK Code

EN62262 ***[EN62262]*** is a standard related to IK ratings that provides an international numeric classification for the degrees of protection provided by enclousres for electrical equipment against mechanical impacts, protecting it contest from external impacts. It was originally defined in the European Standard BS EN 50102 but the standard was renumbered to EN 62262.

1.1. European Standard EN 50155

EN50155 ***[EN50155]*** is an international standard that covers the electronic equipment used on rolling stock in rawilway applications, including aspects as temperature, humidity, shock, vibrations and other parameters providing an example of a tough non-military specification. For example, it extends operating temperature range (−25 – +70 °C) and resistance to humidity.

1.1. NEMA

NEMA ***[NEMA]*** or the National Electrical Manufacturers Association is the association of eletrcial equipment manufactures in the United States. It integrates more than 450 companies and manufacturers related to the electricity or electronic fields. This association publishes more than 600 standards, application guides, white and technical papers.

1.1. IEEE 1156.1-1993

IEEE 1156.1 ***[IEEE1156]*** is a standard specification that provides information and recommendations on the minimum environmental whitstand conditions for the devices. The intent is to achieve uniformitiy and reproducibility in the test conditions for modules. These conditions include, but are not limited to, thermal, mechanical, electrical, and atmospheric stresses.

1.1. FCC mark and CE mark

All electronic devices sold in the United States need to obtain a classification mark by the Federal Communications Commission (FCC) ensuring that the product complies with some standards as:

- Emissions (over other electronic devices or the own radiated by the product).
  - Immunity (response to other electronic devices).

These mark defines two basic kind of devices:

- **Class A**: the product is marketed for commercial or industrial use and is not intended to be used in a home or particular use.
- **Class B**: the product is marketed for residential or home use.

Analogously, for products sold inside the European Economic Area needs to be CE mark compliant of the requirements of the EC directives. Depending on the product and directives to satisfy different numeration is obtained.

1.1. Restriction of Hazardous Substances Directive (ROHS)

It is a short directive for the restriction or avoidment of hazardous sustances (flame retardants, acid, corrosive, etcetera) that could be present in electrical and electronic equipment. It was adopted in February 2003. The directive restricts (with some particular exceptions) the use of some hazardous materials during the manufacturing of various types of electronic equipment, in particular:

- Lead (Pb)
- Mercury (Hg)
- Cadmiun (Cd)
- Hexavalent chromium (CR6+)
- Polybrominated biphenyls (PBB)
- Polybrominated diphenyl ether (PBDE)
- Bis (2-ethylhexyl) phthalate (DEHP)
- Butyl benzyl phthalate (BBP)
- Dibutyl phthalate (DBP)
- Diisobutyl phthalate (DIBP)

1.1. Industrial Automation and Electromagnetic compatibility (EMC)

We can find several directives defined by organisations and standardisation institutes as the International Electrotechnical Commission (IEC), European Commission (EC) or the American Industrial Systems (AIS). The purpose of these normatives about electromagnetic compatibility (EMC) is to maintain all the electromagnetic disturbances and side effects under

different control levels. This can be defined as the ability of certain system to function satisfactorily under its running environment avoiding possible disturbances to other devices or even itself.

One of the most important directives is the EMC 89/336/EEC Directive that is applied to electrical and electronic appliances containing electrical or electronic components liable to cause electromagnetic disturbance and the performance of which is liable to be affected by such disturbance. This directive specifies two requirements:

- A compliant device cannot interfere with the operation of telecommunications equipment.
- A compliant device is immune from electromagnetic interference.

Compliant devices are categorized into two classes: A and B. **Class A** is a more lenient class intended for industrial equipment. **Class B** is intended for devices for use in residential surroundings. All CE-marked equipment from Microstar Laboratories meets the more stringent Class B requirements.

1.2. ISO 9001

Although it is not a specific normative for electrical and electronic device manufacturing, it is an international normative applied to quality management systems. This implies that all the manufacturing process (including management, administration, design and development) ensures the quality of the same process, improving the quality of the products or sevices. All the compliant members must fulfil the strict normative. This normative is recognized by more than 640000 manufactures around the world.

1.3. IEC 60008-2-27 and IEC 60008-2-64

These normatives provide procedures to ensure that products pass a set of specific tests. Two main of the most important are:

- **IEC 60068-2-27**: that provides a standard procedure for determining the ability of a product to resist specified severities of non-repetitive or repetitive shocks in order to reveal mechanical weakness and/or degradation in specified performances, or accumulated damage or degradation caused by shocks. This is mainly used to determine the structural integrity of products as a mean of quality control.
- **IEC 60068-2-64**: that provides a standard procedure for determining the ability to resist dynamic load without unacceptable degradation of its functional and/or structural integrity when is subjected to the specified random vibration test requirements in order to identify the accumulated stress effects and the resulting mechanical weakness and degradation in the specified performance.

1.4. UL 1950/60950

This standard is applicable to mains-powered or battery-powered information technology equipment, including electrical business equipment and associated equipment, with a a voltage not exceeding 600 V. This standard specifies requirements intended to reduce risks of

fire, electric shock or injury for the operator and layman who may come into contact with the equipment and, where specifically stated, for a service person. This standard also specifies requirements intended to reduce risks from acoustic outputs at communication receivers and similar devices used for voice telecommunication, regardless of transmission medium (e.g. wireless network).

1.5. Form factor standards

Form factor standards define the specification for the dimensions, power supply type, location of mounting holes, number of ports on the back panel, etcetera of computer devices. This is an important characteristic for embedded systems in order to design the most appropriate hardware and components, ensuring interoperability amongst different products. There exist a wide range of form factors standards related to industrial and embedded systems, being the most common the next ones:

- SmartModule.
- ETX.
- COM (Express Basic, Expres Compact, Expres Mini).
- PC104 (Plus , Express, PCIe/104).
- UTX.
- XTX.
- Advanced TCA.
- Compact PCI.
- Embedded Compact Extended (ECX).
- Mini-ITX.
- PICMG.
- Pico-ITX.
- PXI.
- VMEbus.
- VPX.
- VXI.
- XMC/PMC.
- 2.5”.
- 3.5”.
- 5.25”.

New form factor standards are constantly appearing due to the evolution of the technology and process manufacturing of electronic devices.

3. Basic hardware and computer types

Depending of the kind of hardware we can find different types of hardware categorized by their main characteristics and properties. It is important to know the basic alternatives on the market that allow to choose the best option for the design purposes.

1.1. Single Board Computer and System on a Chip

Single Board Computers and System on a Chip are computers that integrate microprocessors, memory and input/output pins and interfaces over a single board (SBC) or a

single chip (SoC) compact designs. They ensure to have a complete and ready to use system once they are installed over the final development. These systems are usually cheaper to be built but they not provide slots for capabilities extensions. They are well-suited for embedded solutions.

Figure 2. Single Board Computer Example

Figure 3. System on a Chip Example

1.1. ASIC/FPGA

Application-specific integrated circuits (ASIC) are integrated circuit that are fully customized for a particular application or use. They are designed to fulfil de particular requirements of an application an after them they are built and they can not be programmed by the user. Nevertheless, with the evolution in electronic manufacturing these restrictions can be fuzzy sometimes due to the existence of complex ASICs (that includes a processor, memory, I/O ports, etcetera) that are similar to System on a Chips.

A programmable variation of an ASIC are the Field-Programmable Gate Arrays (FPGA). They are a special kind of integrated circuit that are explicitly designed to be programmed by the system designer. They can be programmed after their manufacturing due they have a structure composed by several logic blocks distributed in a hierarchical and reconfigurable way. These blocks can be reconfigured in order to implement complex combinational functions. Furthermore, they can incorporate memory elements.

Usually this kind of hardware are programmed using Hardware Description Languages (HDL). HDL languages are used to describe the structure and behaviour the electronic and digital logic circuits in a textual way consisting on expressions, statements and control structures.

Figure 4. FPGA Example

1.1. Microcontrollers

Microcontrollers are small computers over a single integrated circuit (usually they are considered System on a Chip) that have a microprocessor, different types of memory blocks and a diverse set of programmable input/output interfaces. Programs are saved in their flash memory blocks. A wide range of microcontrollers can be found on the market, from simple 4 bits and 4KHz frequency clock rates optimized for low power consumption to complex 32 bits processors, integrating full support to wireless communications interfaces.

Figure 5. Microcontroller Example

1.1. PLC (Programmable Logic Controller) and PAC (Programmable Automation Controller System)

Programmable Logic Controllers (PLC) are digital computers specially designed for automation and control of industrial electromechanical processes. They provide multiple digital and analogic inputs and outputs to connect different sensors, actuators, relays and other industrial equipment. The main advantage of the use of PLCs consist on the adaptation facilities to be programed for the final system. Basically programs are real-time sequences in which changes or events of different inputs must be immediately treated to generate new outputs values and so on, running in an infinite loop. In addition, PLCs have integrated different communication ports (usually RS-232, RS-485 or Ethernet) in order to monitorize their execution and results. These computers must be compliant with several electromechanical normatives and directives due their implantation in hard environmental conditions, as extreme temperatures operation ranges, electrical-noise, impact or vibration.

Figure 6. PLC Example

An evolution of PLCs are PACs. Programmable Automation Controllers are industrial technologies for control and automization. They are composed by a controller, different input/output modules and a data bus for data interchanging. It introduces more monitorization and computational resources than a classic PLC. In general the slight differences between PLCs and PACs are summarized in:

- From a programming perspective, a PLC typically has a fixed memory map and addressing whilst a PAC allows tag naming, letting users to define data types. This provides more flexibility, especially when expanding the system.
- Typically PACs offer much greater I/O capacity and user memory size for larger projects and larger overall system sizes.
- PACs offer more built-in features such as USB data logging ports, a web server to view system data and data log files, and an LCD screen for enhanced user interface and diagnostics (Figure 2).
- PACs are designed to be integrated more tightly with SQL and other databases. They often are still the choice for process control applications because they deliver other advantages such as standard 16-bit resolution analog for higher precision measurements.

Nevertheless, modern PLCs and PACs share many of the same features, and either will work in many applications.

Figure 7. PAC Example

1.1. Embedded PC - Box Computer

An embedded computer is a particular PC designed to perform a specific set of tasks. That means that its hardware and software is fully optimized to do the programmed actions with the best performance. The hardware integrates all the interfaces, microprocessors and memory that the designed job needs. Usually these computers have a small size and are integrated into a single board. Finally, some particular restrictions as resilience, fanless, silent design and low power consumption are key aspects of its design.

Figure 8. Embedded PC Example

Nevertheless, with the advance of technology, powerful designs have derived to small multi-purpose computers that fulfils the above designed jobs. Users can buy these products for designing and developing their own solutions or to achieve their particular needs. For this reason, the concept of Box computer (that is an embedded/small computer encapsulated in to a chassis) is becoming popular due it can be purchased by particular users for their particular needs. Depending on the type of the computer different sizes and interfaces will be available.

Figure 9. Box Computer Example

1.1. Industrial PC

Industrial PCs are PCs with specific designs and structures to perform in industrial environments. They are usually employed for process control and data acquisition. Usually applications consist on reading and writing the I/O cards plugged inside the PC. They must face with hard conditions of industrial environments, for this reason, they should fulfil similar characteristics as:

- Heavy metal chassis construction (rugged chassis).
- Standard enclosure and/or form size factor to be mounted in the surrounding environment (19”rack, wall mount, panel mount, and etcetera).
- Special cooling design and air filtering. They can use complex forced air, liquid or conduction refrigeration systems.
- A wide set of expansion card slots.
- Fulfil with several Electro-Magnetic emission normatives.
- Robust interfaces.
- Inclusion of mechanisms to reset the automatically the system in case of system disfunction (watchdog timer).

Figure 10. Industrial PC Example

1.1. Rugged/Hardened device

A rugged or hardened device (computer, board, and etcetera) is a device specifically designed to operate reliably under harsh usage conditions and environments. That include strong vibrations, wet or dusty conditions and extreme temperatures. It implies that internal hardware and electronic, external housing or case and it software must work under the operation conditions.

Electronic components are selected for their ability to withstand in higher and lower temperatures and strong vibrations whilest the external cases protect them from dust, water and other environmental conditions. Rugged computers also integrates fully sealed keyboards to protect against intrusion by dust or liquids, and scratch-resistant screens that are readable in direct sunlight. Obviusly rugged units are more expensive in terms of hardware costs. There are three generally accepted levels of ruggedization depending on the ability of survive to drops, vibrations, dust, inmersions and extreme temperatures:

- Semi-rugged (commercial): that are being called business-rugged by the marketers are usually enhanced versions of commercial off-the-self (COTS) hardware in which the components are the same butt they are protected better.
- Fully-rugged (Rugged): that are designed from the inside-out work in extreme temperatures to be impervious to being dropped, to resist shocks and vibrations and to be dustproof and waterproof.
- Ultra-rugged (Military): that are usually designed to meet precise specifications for military use and to be employed in the hardest environmental scenarios.

The two most common ruggardization values to identify the properties are Ingress Protection (or IP Code) and MIL STD 810.

Figure 11. Rugged Device Example

4. Wireless Sensor Network Platforms

4.1. CM5000 - TelosB

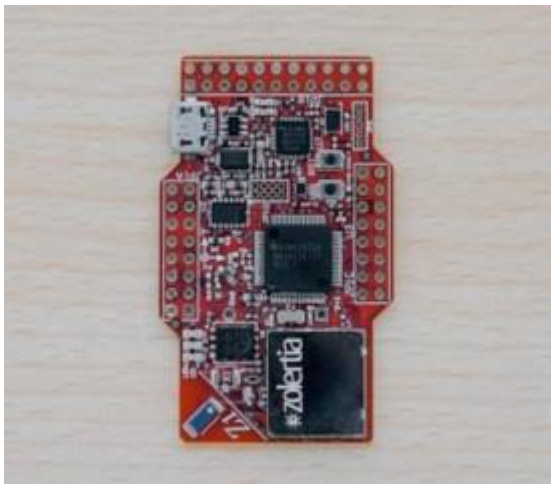
The CM5000 is an IEEE 802.15.4 compliant wireless sensor node based on the original opensource TelosB platform design developed and published by the University of California, Berkeley. The included sensors in this mote version can measure temperature, relative humidity and light.

Processor			
Processor Model	Texas Instruments® MSP430F1611	Texas Instruments® MSP430 family	
Memory	48KB	Program	flash

	10KB 1MB	Data RAM External Flash (ST® M25P80)
ADC	12bit resolution	8 channels
Interfaces	UART, SPI, I2C USB	Serial Interfaces External System Interface (FTI® FT232BM)
Radio		
RF Chip	Texas Instruments® CC2420	IEEE 802.15.4 2.4GHz Wireless Module
Frequency Band	2.4GHz ~ 2.485GHz	IEEE 802.15.4 compliant
Sensitivity	-95dBm typ	Receive Sensitivity
Transfer Rate	250Kbps	IEEE 802.15.4 compliant
RF Power	-25dBm ~ 0dBm	Software Configurable
Range	~120m(outdoor), 20~30m(indoor)	Longer ranges possible with optional SMA antenna attached
Current Draw	RX: 18.8mA TX: 17.4mA Sleep mode: 1uA	Lower RF Power Modes reduce consumption
RF Power Supply	2.1V ~ 3.6V	CC2420 Input Power
Antenna	Dipole Antenna / PCB Antenna	Additional SMA connector available for extra antenna
Sensors		
Light 1	Hamamatsu® S1087 Series	Visible Range (560 nm peak sensitivity wavelength)
Light 2	Hamamatsu® S1087 Series	Visible & Infrared Range (960 nm peak sensitivity wavelength)

Temperature & Humidity	Sensirion® SHT11	Temperature Range: -40 ~ 123.8 °C Temperature Resolution: : ± 0.01(typical) Temperature Accuracy: ± 0.4 °C (typical) Humidity Range: 0 ~ 100% RH Humidity Resolution: 0.05 (typical) Humidity Accuracy: ± 3 %RH (typical)
Electromechanical Characteristics		
Dimensions	81.90mm x 32.50mm x 6.55mm	Including USB connector
Weight	17.7g	Without batteries
Power	3V (2xAA Battery Holder Provided)	MICREL® MIC5207 Power Regulator
Environment and		
Temperature range	-40ºC ~ 125ºC	

4.2. Zolertia Z1



One of the most used hardware development platforms in Wireless Sensor Networks around the world. Z1 is equipped with a second generation MSP430F2617 low power microcontroller, 8KB RAM and a 92KB Flash memory. Also includes the well-known CC2420 transceiver, IEEE 802.15.4 compliant, which operates at 2.4GHz with an effective data rate of 250Kbps.

Processor		
Processor Model	Texas Instruments® MSP430F2617	Texas Instruments® MSP430 family
Memory	92KB	Program flash 8KB Data RAM
ADC	12bit resolution	8 channels
Interfaces	UART, SPI, I2C USB	
Radio		
RF Chip	Texas Instruments® CC2420	IEEE 802.15.4 2.4GHz Wireless Module
Frequency Band	2.4GHz ~ 2.485GHz	IEEE 802.15.4 compliant
Sensitivity	-95dBm typ	Receive Sensitivity
Transfer Rate	250Kbps	IEEE 802.15.4 compliant
RF Power	-25dBm ~ 0dBm	Software Configurable
Range	~120m(outdoor), 20~30m(indoor)	Longer ranges possible with optional SMA antenna attached
Current Draw	RX: 18.8mA TX: 17.4mA Sleep mode: 1uA	Lower RF Power Modes reduce consumption
RF Power Supply	2.1V ~ 3.6V	CC2420 Input Power
Antenna	Dipole Antenna / PCB Antenna	Additional SMA connector available for extra antenna
Sensors (embedded)		
Accelerometer	ADXL345	Visible Range (560 nm peak sensitivity wavelength)
Temperature	TMP102	Temperature Range: -40 ~ 123.8 °C Temperature Resolution: : ± 0.01(typical) Temperature Accuracy: ± 0.4 °C (typical)

Electromechanical Characteristics		
Dimensions	56.8mm x 34.5mm	Including USB connector
Power	3V (2xAA,AAA batteries or USB)	CP2102 Power Regulator

Environment and encapsulation

Temperature range	-40ºC ~ 125ºC

4.3. Zolertia Re-mote

The redesigned and improved version of the Z1, just released in the market, provides some better specifications that may render this hardware the solution selected for any current project with WSN. The RE-Mote includes a multiband antenna to start sending data from the first moment.

Also, the RE-Mote Suite includes in addition the white enclosure, the LiPo battery, Phidgets and Ziglet connectors, too. Everything connected and fixed. Select your best option under this description. - See more at: http://zolertia.io/product/hardware/re-

mote#sthash.QYFu9rra.dpuf

Processor		
Processor Model	Texas Instruments® CC2538	ARM 32-bit Cortex-M3 microcontroller 32Mhz
Memory	512KB 32KB	Program flash Data RAM
ADC	12bit resolution	8 channels
Interfaces	UART, SPI, I2C	Micro-SD card
Radio		
RF Chip	2 Texas Instruments® RF: CC2420 CC1200	IEEE 802.15.4 2.4GHz Module IEEE 802.15.4 868/915Mhz Module
Frequency Band	2.4GHz ~ 2.485GHz 868 ~ 915Mhz	IEEE 802.15.4 compliant
Sensitivity	-97dBm typ	Receive Sensitivity
Transfer Rate	250Kbps	IEEE 802.15.4 compliant
RF Power	-25dBm ~ 7dBm	Software Configurable
Range	~120m(outdoor), 20~30m(indoor)	Longer ranges possible with other SMA antenna attached
Current Draw	RX: 20mA TX: 24mA Sleep mode: 1uA	Lower RF Power Modes reduces consumption

RF Power Supply	2.0V ~ 3.6V	CC2520 Input Power
Antenna	Dipole Antenna / PCB Antenna	Additional SMA connector available for extra antenna
Sensors (embedded)		
Accelerometer	ADXL345	Visible Range (560 nm peak sensitivity wavelength)
Temperature	TMP102	Temperature Range: -40 ~ 123 °C Temperature Resolution: : ± 0.01(typical) Temperature Accuracy: ± 0.4 °C (typical)
Electromechanical Characteristics		
Power	built-in battery charger and powered from 3-28V.	
Environment and encapsulation		
Temperature range	-40ºC ~ 125ºC	

4.4. OpenMote-CC2538.

Processor		
Processor Model	Texas Instruments® CC2538	ARM 32-bit Cortex-M3 microcontroller 32Mhz
Memory	512KB 32KB	Program flash Data RAM
ADC	12bit resolution	8 channels
Interfaces	UART, SPI, I2C	
Radio		
RF Chip	Texas Instruments® CC2520	IEEE 802.15.4e 2.4GHz Wireless Module
Frequency Band	2.4GHz ~ 2.485GHz	IEEE 802.15.4 compliant

Sensitivity	-97dBm typ	Receive Sensitivity
Transfer Rate	250Kbps	IEEE 802.15.4 compliant
RF Power	-25dBm ~ 7dBm	Software Configurable
Range	~120m(outdoor), 20~30m(indoor)	Longer ranges possible with optional SMA antenna attached
Current Draw	RX: 20mA TX: 24mA Sleep mode: 1uA	Lower RF Power Modes reduce consumption
RF Power Supply	2V ~ 3.6V	CC2520 Input Power
Antenna	Dipole Antenna	
Sensors (embedded)		
Accelerometer	ADXL345	
Temperature	TMP102	Temperature Range: -40 ~ 123.8 °C Temperature Resolution: : ± 0.01(typical) Temperature Accuracy: ± 0.4 °C (typical)
Electromechanical Characteristics		
Dimensions	2.438 cm x 3.294 cm	Xbee Form factor (XBee Explorer USB Dongle compatible)
Power	3V (2xAA,AAA batteries)	
Environment and encapsulation		
Temperature range	-40ºC ~ 125ºC	

4.5. SAM R21 Xplained Pro

Processor		
Processor Model	ATMEL ATSAMR21G18A	Single-chip ARM® Cortex®-M0+ based 32-bit Microcontroller
Memory	256 KB Program flash 32 KB SRAM	
ADC	12bit resolution	8 channels
Interfaces	UART, SPI, I2C USB	
Radio		
RF Chip	Atmel AT86RF23x	IEEE 802.15.4 2.4GHz Wireless Module
Frequency Band	2.4GHz ~ 2.485GHz	IEEE 802.15.4 compliant
Sensitivity	-101dBm typ	Receive Sensitivity
Transfer Rate	250Kbps	IEEE 802.15.4 compliant
RF Power	+4dBm	Software Configurable
Range	~120m(outdoor), 20~30m(indoor)	Longer ranges possible with optional SMA antenna attached
RF Power Supply	1.8V ~ 3.6V	CC2420 Input Power
Antenna	Dipole Antenna / PCB Antenna	Additional SMA connector available for extra antenna
Electromechanical Characteristics		
Dimensions	56.8mm x 34.5mm	Including USB connector
Power	3V (2xAA,AAA batteries or USB)	CP2102 Power Regulator
Environment and encapsulation		
Temperature range	-40ºC ~ 125ºC	

5. Industrial hardware and peripherals

Critical systems can not be performed with common desktop computers, especially applications for industrial control, power efficiency, high-availability, and etcetera. Industrial hardware and peripherals are completely designed and tested to operate under the specified conditions (temperature ranges, air quality, shock, vibration, etcetera) and requirements of these environments. In next sections, we provide a representative list of manufacturers and products that can be used for industrial purposes.

4.1. AMD

AMD ***[AMD]*** offers the AMD G Series that is a complete System-on-chip solution that integrates a powerful GPU and I/O controller for the development of embedded applications. It is designed for low-power and high-performance designs as Industrial Control and Automation or Electronic Gaming Machines. Its main features are:

- Diverse range of CPU options from 2 cores at 800MHz to 4 cores up to 2GHz.
- Temperature of operation from -40º to 105º.
- Power consumption from 5W to 25W.
- Integrates a graphic core (GPU) with DirectX 11 support.
- DDR3 integrated memory.
- HDMI, DVI and VGA interfaces for output display.
- PCIe, USB 2.0 and USB 3.0, SATA and SD car reader interfaces controllers.

Figure 12. AMG G Series

4.2. Texas Instruments

Texas Instruments ***[TexasInstruments]*** is one of the main manufactures of electronic devices on the world. The range of products for embedded systems are divided in:

- **Low-power MCUs**: that are composed by low-power 16-bit and 32-bit microcontrollers. They have advanced features to operate in low-power modes with less de 1us for wakeup. The most common microcontroller integrates a 48-MHz ARM Cortex processer, 128 bit of flash memory, 64KB of RAM memory, 8 channels for input/output and JTAG, UART, I2C and SPI interfaces.
- **Performance MCUs**: that are composed by microcontrollers of the 32-bit architecture C2000 MCU family. They are specially designed for real-time control applications as motor control or digital power supplies. All the products have integrated a mathematical hardware accelerator to increase the performance of the trigonometric functions common in many motor control algorithms. Also, extra

peripherals complement the basic structure including PWM generator, ADC conversors and enhanced capture units. Finally different communication ports as USB, Ethernet, I2C, UART, SPI, CAN and LIN are available for different models.

- **Wireless MCU**: that is based on an integrated 80-MHz ARM Cortex microcontroller with a Wi-Fi certified module. This microcontroller offers 256KB of flash memory for the application code with different integrated interfaces as I2S audio, parallel camera, SDMMC, ADC, SPI, UART, I2C, PWM and different I/Os devices. The microcontroller support Free RTOS or TI-RTOS. This microcontroller can be used for Internet-on-a-chip applications (email from link, XMPP, Information center, http server, etcetera), Wi-Fi apps (AP modes, Easy Wi-Fi Configuration, TCP/UDP applications) or MCU peripheral samples apps.

Also for personal use or prototyping the TI LaunchPad is created. The concept follows a similar approach to the Arduino platform, both in hardware and software tools. This product integrates different versions of development boards, offering 16-bit to 32-bit processors depending on the product. These boards offer I2C, SPI and UART communication interfaces, different amount of Input/Output pins and 16KB to 1MB of non-volatile memory. Advanced devices integrate support for different connectivity interfaces and protocols ad Wi-FI, Ethernet, USB, CAN.

Figure 13. Texas Instruments Launchpad

4.3. National Instruments

National Industrial ***[NationalInstruments]*** offers a wide range of alternatives for industrial programming and automation control. Some of their solutions for industrial environments are:

- **Real-time controllers**: that are industrial fanless controllers designed for a highperformance. They integrate the LabView Real-Time operating system running on Intel Celeron up to 1.66 GHz. They have different interfaces for their connectivity

with other industrial devices, including Gigabit Ethernet ports and PCI slots for additional expansion.

- **myRIO**: is a prototype and research hardware embedded device specially designed for the use of students able to implement complex designs. It is based on a processor, a reconfigurable FPGA, different inputs and outputs and also is graphical design software providing the ability to rapidly create custom hardware circuitry with highperformance Input/Output.

Figure 14. National Instruments myRIO

4.4. Advantech

Advantech ***[Advantech]*** is a manufacturer for different Industrial PCs compatible with OPC and OPC-UA programming language. One of the best products is the APAX-5580 Control IPC that is a PC-based control platform with comprehensive I/O modules, communication ports, and control software. It is particularly designed to take advantage of the trend in Industry 4.0. It is structured in a DIN-Rail PC Controller with an Intel Core i7/i3/Celeron CPU. It can be combined with APAX I/O modules, and flexible I/O expansion, real-time I/O control, network capability through various interfaces, and support dual power input and UPS module for robust power system. It also has a built-in the standard mini PCI express interface for wireless communication. Its main features are:

- 4th Generation Intel® Core™ i7/i3/Celeron Processors up to 1.7 GHz with 4GB/8GB DDR3L Memory.
- 2 x GbE, 4 x USB 2.0/3.0, 1 x RS-232 /422/485, 1 x VGA, Audio.
- Dual power input and UPS support.
- Compact with Fanless Design.
- Supports Fieldbus Protocol.
- 3G/GPS/GPRS/Wi-Fi Communication interfaces.
- Chassis with grounding protection.
- Support for LAN redundancy.
- Fault-Protected RS-485 transceivers.
- 10 year lifetime for the RTC battery.

Figure 15. Advantech APAX-5580

4.5. Artila

Artila Electronics ***[Artila]*** is a manufacturer focused on the design and developing of flexibly-programmed industrial solutions using ARM-based and Linux architectures. They provide a wide catalogue of products, being the most significative the next ones:

- **Intelligent IoT Gateway**: that integrates a Low Power ARM for wide temperature running a Linux distribution in a very size small. It can be expanded with different communication interfaces WLAN, 3G, USB, etcetera. It is ready to be ready to work directly with Web, FTP, Email, SNMP, PHP and Java. Although they are designed to act as Gateways they can be used as Industrial Box Computer.

Figure 16. Artila IoT Gateway

- **Programmable Automation Controllers based on ARM architecture**: they are isolated until 2500Vrms. Also their digital and analog inputs and outputs are isolated too. They integrate RS-232 and USB ports as communication interfaces. Furthermore they periodically publish data and events to a server using the MQTT protocol.

Figure 17. Artila PAC

- **Web-based remote I/O**: that are devices designed for the remote control and management of industrial I/O by means of the enabling of an AJAX web Interface. They support Modbus TCP and integrate a FreeRTOS as an operating system.

Figure 18. Artila Remote IO

- **IoT Device Platform**: that are complete solutions of Single Board Computers ready to be used on industrial environments. They integrate an ultra low power 32-bit ARM processor in a compact 50x80mm footprint card. They are able to run a Linux operating system.

4.6. ADLink

Adlink ***[ADLink]*** has a wide range of products focused on industrial and embedded systems making available different solutions for each king of application system. Inside the whole products division, the most interesting solutions are:

- **Computer-on-modules**: that are specially designed to build IoT devices. Inside these solutions we can found a SoC composed by an Intel Atom E3800 Series and Celeron N2930/J1900 Processor integrated with 4 GB DDR3L at 1333 MHz memory with dual channel 24-bit LVDS and VGA, 2x SATA and 2x PATA (M/S), 4x USB 2.0 and 10/100 Mbps LAN.

Figure 19. Adlink Computer on module

- **Industrial PCs**: offering fanless, cable-free, robust mechanisms in a compact form factor computer. The rugged design provides reliable performance in mission-critical harsh environments. The product range of Industrial PCs are based on Intel Atom or Intel i7 core processors and they have support for several interfaces and connectors.

Figure 20. Adlink Industrial computer

- **Industrial Motherboards and SBCs**: offering fanless operation over extreme temperature, resistance to shock and vibration, conformal coating, embedded BIOS, and a long product lifetime. They are based on Vortex or Intel Atom processors with integrated RAM memory and GPIO pins for device expansion.

Figure 21. Adlink Industrial Motherboard

- **Rugged systems**: offering different products for operating in harsh conditions. One example is the model HPERC-IBR-HC that provides a system with Intel i7 processor with 8GB of RAM memory and Ethernet, SATA and USB interfaces to opérate in extreme temperaturas (-40º to 85ºC).

Figure 22. AdLink HPERC-IBR-HC

4.7. EVOC

EVOC ***[EVOC]*** is a manufacturer specialized on the design and development of Single Board Embedded computers. It offers a wide range of standards and sizes including the common used 104, 3.5”, EPIC, 5.25”, Mini-ITX, Micro-ITX and ATX based on x86 structure (ATOM, Sandy Bridge, Ivi Bridge, Haswell) working over harsh application environments as military industry and field exploration in temperature range of -40º to 85º. The most representative products are:

- **EC3-1641CLDNA**: is a Single Board Computer with a size of 3.5" with Onboard AMD GeodeTM LX800 500MHz CPU, fanless design. It has a 256MB DDR RAM memory and it is able to run Windows Operating System. It integrates different interaction interfaces as VGA, LVDS, LCD, LAN and audio. Also USB, serial and parallel ports are available.

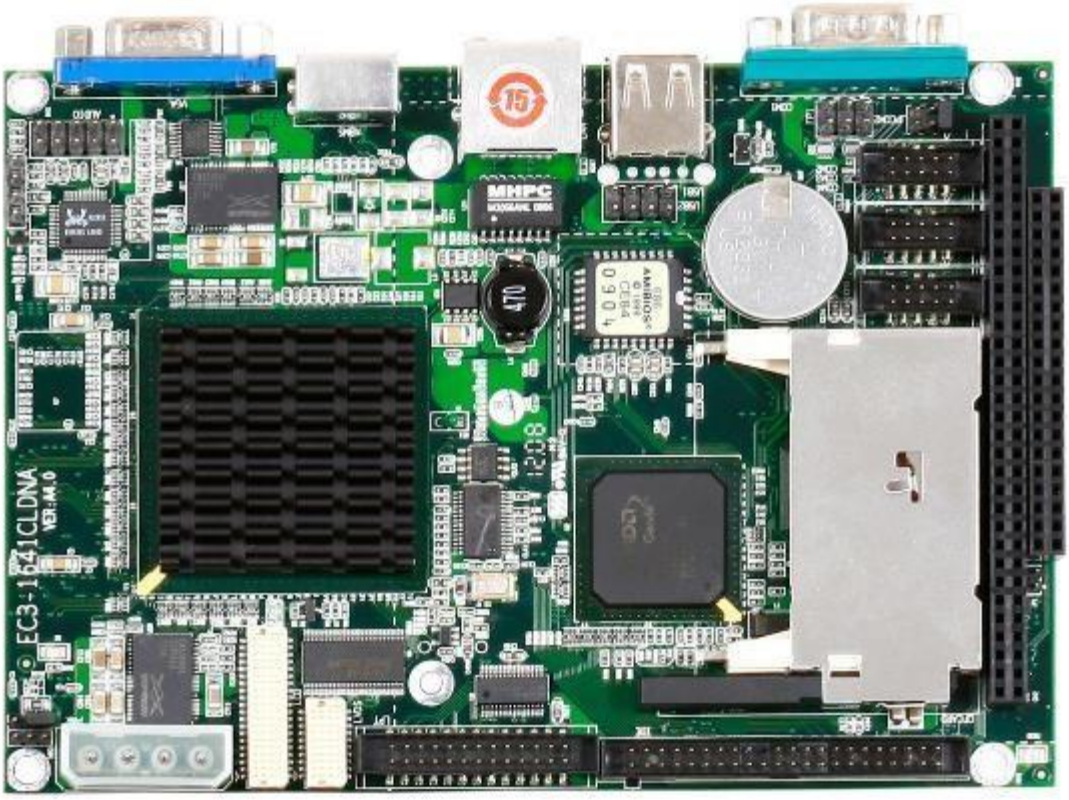


Figure 23. EVOC 1641 CLDNA

- **104-1816CL2NA**: is a Single Board Computer using the 104 size standard with Intel Bay N2930 processor up to 1.83GHz and 4GB of DDR memory RAM. It has 8 channel Input/Output pins, 4 serial ports, 3 USB ports (supporting USB 3.0) and different interfaces for connecting displays to the board (VGA, LVDS). Finally it has a PCI-104 expansion bus slot.

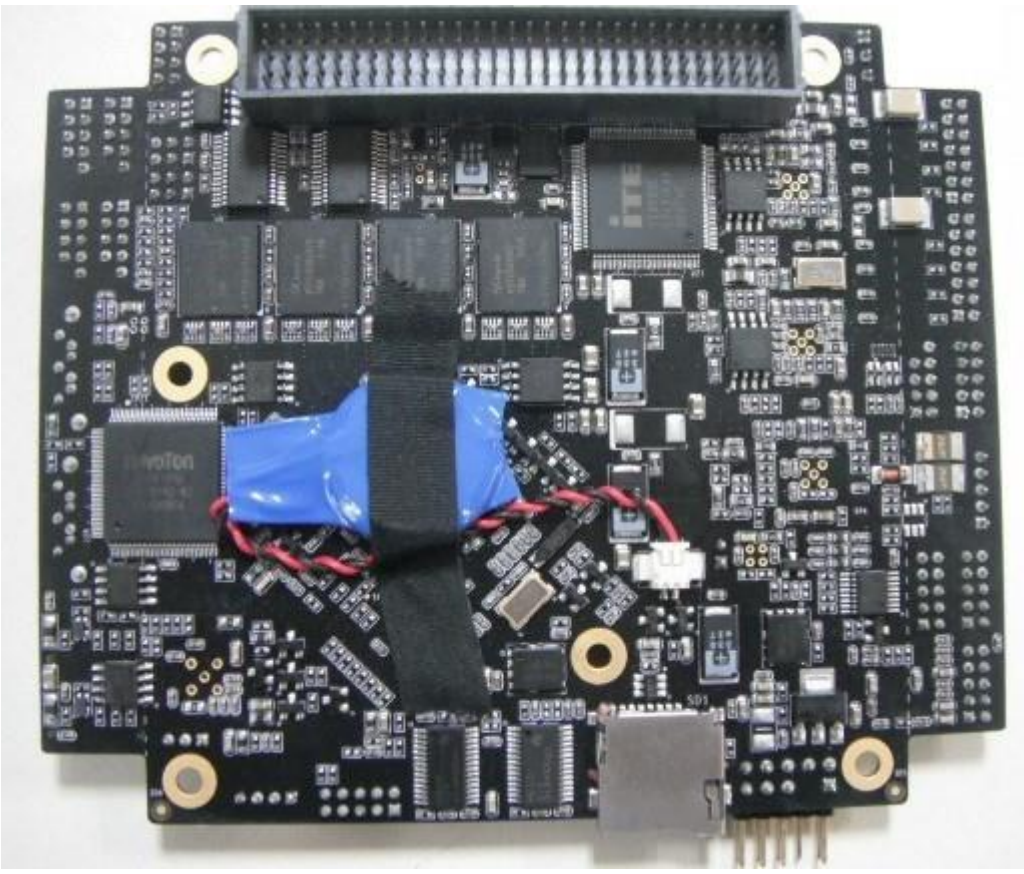


Figure 24. EVOC 1816 CL2NA

- **MEC-5071**: is a Box computer suited for embedded appliances. It has an Intel I7 Core processor supporting up to 16GB of memory capacity. Its main feature is to have a wide range of connectors and interfaces as 8 pin GPI, 6 USB ports, 2 LAN interfaces, 6 RS-232/422 ports, 1 parallel port and different audio and video connectors including HDMI, VGA, DVI and LVDS. Also 6 different expansion slots are available. Finally, the system supports different operating systems as Windows, Linux or VxWorks.

Figure 25. EVOC MEC 5071

4.8. Acrosser

Acrosser ***[Acrosser]*** develops different industrial and embedded computers systems. On one hand its industrial computers can be categorized in three sectors depending on his size and features: half-size fanless card, backplane and industrial peripheral cards. All these products support from 3 to 6 ISA slots and are well-suited for work over harsh industrial environment in machine control, factory automation and power factory monitoring. It is also remarkable that there are available different chassis sizes to integrate these computers on different allocations such as industrial automation and automobile computer vendors.

On the other hand embedded computers are available in two types: fanless embedded system and embedded system with fan. Both are designed for harsh environment and industrial automation controls. These computers provide scalable Intel Atom, Celeron, Core i, Core 2 Duo platforms to fulfil the application needs. Also, the computers support the flexible expansions, including: Mini PCIe, PCIe, PCI, Wi-Fi, 3.5G, etc. The systems can perform either with Windows or Linux.

Figure 26. Acrosser Embedded Computer

4.1. Addi-data

Acrosser ***[Addi-data]*** develops Programmable Automation Controllers (PACs) specially designed for real-time industrial measurement, control and automation applications. These devices have a modular platform that allows the distributed measurement and control in realtime. The PACs follow standard sizes and format for their chassis as PCI or CompactPCI. A Real-Time Linux operating system are installed ready to use.

Figure 27. Addi-data PAC

4.1. ESA-Automation

ESA-Automation ***[ESA-Automation]*** is a manufacturer that offers a wide range of solutions for industrial automation and computation as industrial Box PCs, PLC and PACs. It most remarkable products are:

- **EW400 Rugged Box PC**: that is a fully configurable Box-PC for industrial harsh conditions. It has a fanless design and integrates an innovative heat dissipation system allowing working in -20º to 60º range. It has support to Intel i7 Core processor and has support to several communication interfaces, including USB 3.0, CFast and PCIe/PCI expansions.

Figure 28. ESA Automation EW400 Rugged Box PC

- **PAC Box ARM/1000**: that it is a complete solution integrating a PLC, Motion Control, CNC and IT server that can be used both as "Master or Slave" inside a HMI architecture. Equipped with an ARM Cortex (Box ARM) or Intel Atom (Box 1000) processor this PAC provides 20 digital inputs and 20 digital outputs up to 24 Vdc and 1,2A of max current completely configurable by jumpers. IT provides up to 1GB of memory and has integrated different interfaces as USB, RS-232, Ethernet, Modbus, USB, CAN and RTC.

Figure 29. ESA Automation PAC Box

4.2. Mosaic Industries

Mosaic Industries ***[Mosaic]*** offers different solutions for Single Board Computers for embedded systems. It most remarkable products are:

- **PDQ Board**: that is a fast microcontroller specially designed for data acquisition and instrument control. It has a palm size (2.5" by 4") fitting in any space-constrained applications. It holds a Motorola 16-bit HCS12 microprocessor up to 20MHz clock. It incorporates dozens of analog and digital I/O lines and interfaces for serial communications (RS-232, SPI and IIC). In detail, it delivers 8 digital I/O lines with counter/timer capabilities, 8 PWM digital output signals and 8 general purpose digital I/O lines. Also it can be expanded with different expansion modules including Ethernet, WiFi and GPS.

Figure 30. Mosaic PDQ Board

- **QCard**: that is a small footprint single board computer of 2" by 2.5" size. It is well suited for interfacing to sensors and actuators in machine automation and industrial control. It is delivered with a Motorola 68HC11F1 processor up to 16MHz with 512KB of Flash memory and 128KB of RAM memory. It offers 8 lines of programmable digital I/O, 8 lines of 8-bit analog to digital conversion and support to RS232/485. Also it can be expanded with different expansion modules including Ethernet, WiFi and GPS.

Figure 31. Mosaic QCard

4.3. Unitronics

Unitronics ***[Unitronics]*** offers a PLC with integrated display solution (HMI) to be applied to industrial applications. These integration brings facilities as reduced programming efforts due to the use of a single programming environment both for the PLC and the HMI interface. Also les space is required to maintain both solutions reducing the amount of wiring between the interfaces.

Figure 32. Unitronics PLC

4.1. iBase

iBase ***[iBase]*** is a manufacturer of embedded systems solutions offering SBC, Mini-ITX, CPU module, CPU card and industrial motherboards for embedded system and different applications in the automation, digital signage, gaming, retail, medical, military and transportation markets. Its products varies from AMD Geode and Intel Celereon to the latest products on the in different form factors.

4.1. Gateworks

Gateworks ***[Gateworks]*** offers Single Board Computers especially designed for embedded wireless and wired network applications. They are based on ARM processors. Next we show a selection of its products are:

- **Ventana GW5410 Single Board Computer**: that is a high performance board that include six PCIe sockets. It has an ARM Cortex A9 Quad Core processor up to 1GHz. Also it provides 1GB of DRAM and up to 256MB of flash memory. It can support any combination of 802.11, 3G/4G and WiMAX radio interfaces. It provides embedded features such as real time clock, voltage, temperature monitor, fan control, programmable front panel switch and others. It is able to shut-down and wake-up from remote applications. Finally it can work with different operating system as OpenWrt, Android, OpenEmbedded Linux and Windows Embedded Compact 7.

Figure 33. Gateworks Venta GW5410

- **Ventana GW5520 Single Board Computer**: that is a high performance dual core Single Board computer integrating two Mini-PCIe sockets and offering a good performance for multimedia applications. It integrates an ARM Dual Core A9 processor up to 800MHz with 512MB of DRAM and 256MB of memory flash. It supports. OpenWrt, OpenEmbedded/Yocto and Android operating systems.

Figure 34. Gateworks 5520

- **Ventana GW5100 Single Board Computer**: that is a small sized (35x100mm) SBC integrating Gigabit Ethernet, USB and HDMI output. It features an ARM Cortes A9 processor up to 800Mhz integrating 512MB of DRAM and 256 MB of System Flash. OpenWrt, Android and OpenEmbedded Linux operating systems are supported.

Figure 35. Gateworks 5100

4.1. IC Nexus

IC Nexus ***[ICNexus]*** is a manufacturer specialized on the design of ARM based solutions for embedded systems. Inside the range of products we can remark the next ones:

- **SBC2100**: that is Single Board Computer integrating an iMX6 Cortex A9 processor running at 1GHz with power consumption. It provides different interfaces and offers support for I2C and enables a GPI. Also, it has over voltage protection.

Figure 36. IC Nexus SBC2100

- **SBC1400**: that is a Single Board Computer that integrates an ARM11 CPU running at 700 MHz for reliable computing performance. It is able to manage a MPEG-1/2/4 / H.264 video decoder up to 1080p and H.264 video encoder up to 720p performance. It provides TTL, LVDS and HDMI display interfaces. Also provides interfaces for 10/100 Mbps Ethernet, USB 2.0/1.1, SATA, microSD card storage interfaces and RS232/RS-485 interfaces. It supports Android 2.3, Linux 2.6 and Windows CE 6.0.

Figure 37. IC Nexus SBC1400

4.2. IPC2U

IPC2U ***[IPC2U]*** offers different solutions to be applied in industrial environments. Its range varies from classic 19" computer systems and components of modern compact computers to Panel PC display solutions and digital signage devices. Industrial network devices such as rugged network switches and gateways as well as controllers for typical industrial control applications such as CAN and MOD-bus connections are also available. Some of the most remarkable products are:

- **uIBX-230-BT-N2/2G-R11**: that is an Embedded Server integrating an Intel Celeron N2930 up to 1.83GHz. It has available 2GB of DDR3 RAM. It offers interfaces for VGA, RS-232, GBit LAN, USB and Audio. It has a fanless aluminium chassis and it has a temperature range of operation from -20º to 60º.

Figure 38. IPC2U uIBX-230-BT

- **HBJC501F9Q-Q87-B**: that is an Embedded Mini-PC that supports the 4th Generation of Intel Core CPU. It integrates up to 16GB DDR3L memory and enables interfaces for HDMI, DVI, and two LAN connectors, Serial, USB and SATA. It can support Intel Core i3, Intel Core i5 and Intel Core i7 processors inside a fanless aluminium chassis.

Figure 39. IPC2U HBJC501

- **NISE-2210-500G-DNM-W7**: that is an embedded computer based on Intel Atom D2550 at 1.86 GHz. It integrates 4GB DDR3 RAM memory that integrates interfaces for DVI-I, HDMI, two LAN connectors, serial communications. Also it has an internal hard drive of 500GB. It runs Windows Embedded Standard 7 in a fanless aluminium chassis.

Figure 40. IP2U NISE-2210

- **ARK-1120F-N5A1E**: that is a fanless embedded server integrating an Intel Atom N455 1.66GHz, up to 2 GB DDR3. It offers interfaces VGA, serial ports, USB, LANConstruction Chassis: Aluminium Chassis. It has a fanless chassis working in the 0º to 40ºC temperature range.

Figure 41. IPC2U ARK-1120

- **NISE-103**: that is an embedded server based on Intel Atom D425 1.8GHz with 2GB DDR3 RAM. It offers interfaces for VGA, 2 LAN connectors, various serial port interfaces, USB, CF Socket and a Mini-PCIe slot in a fanless chassis working in the 5º to 55ºC temperature range.

Figure 42. IPC2U NISE-103

4.3. OMRON

OMRON ***[OMRON]*** is one of the most common manufacturers of electronic instrumental. It has a wide range of PLC for their implantation in industrial environments. We can distinguish the next types:

- **Compact PLCs**: focused on the development of small and compact applications. They integrate an Ethernet port and are able to manage until 320 I/O digital positions. Also they provide interfaces for DeviceNet, CompoBus/S, Profibus-DP and CAN.

Figure 43. OMRON Compact PLC

- **Modular PLCs**: that are modular PLC that integrate different architectures for communication supporting (Ethernet, USB, Serial ports, and etcetera). Also, they are able to manage until 2560 I/O digital positions. Interfaces for DeviceNet, CompoBus/S, Profibus-DP, Profibus-IO and CAN are provided.

Figure 44. OMRON Modular PLC

- **Frame PLCs**: that are fully compatible with the modular PLCs are able to manage until 5000 I/O digital positions. They have the most powerful computing process speed of their products.

4.4. Sinetic

Sinetic ***[Sinetic]*** is a manufacturer that has in their catalogue a wide range of industrial box computers. The most significative ones are:

- **iSBX-6702-W6485E**: that is an embedded Box PC featured with 6 USB ports, 6 serial ports, different video interfaces, Gigabit LAN and supports a wide range of power input voltage from 9 to 36VDC. It has support for Intel Core i3/i5/i7 processors with low power consumption (15W). It can manage until 8GB of RAM memory. Finally, it has a wide operating temperature range from -40º to 70ºC.

Figure 45. Sinetic iSBX-6702

- **iSBX-6712-3317U**: that it is a fanless embedded Box PC featured with 6 USB ports, 4 serial ports and a Gigabit Ethernet LAN interface. It has an Intel Core i5 processor with 4GB (supporting up to 8GB). It integrates different expansion slots for PCI o PCIe.

Figure 46. Sinetic iSBX-6712

4.1. Toradex

Toradex ***[Toradex]*** is an enterprise that focuses its work on the design and development of computer on module and single board computers for industrial purposes. It offers different System on Chips (SOC) based on ARM processors. Its main products are categorized in two families:

- **Apalis family**: that are focused on provide optimal balance between graphics management and power consumption. Also they provide several multimedia interfaces.

Figure 47. Toradex Apalis

- **Colibri family**: that are focused on provide small form factor Single Board Computers complemented with the presence of many industrial and connectivity interfaces.

Figure 48. Toradex Colibri

4.1. VTI Instruments

VTI Instruments ***[VTIInstruments]*** is an enterprise that offers different solutions for industrial applications. It is an integrator of products having the philosophy of "no one platform is ideal for every application". One of the main products are:

- **EX1200**: that is a LXI mainframe for integrated high-density precision switching and I/O CMX PX as well as applications that require low-density precision switching and I/O to be integrated with instruments.

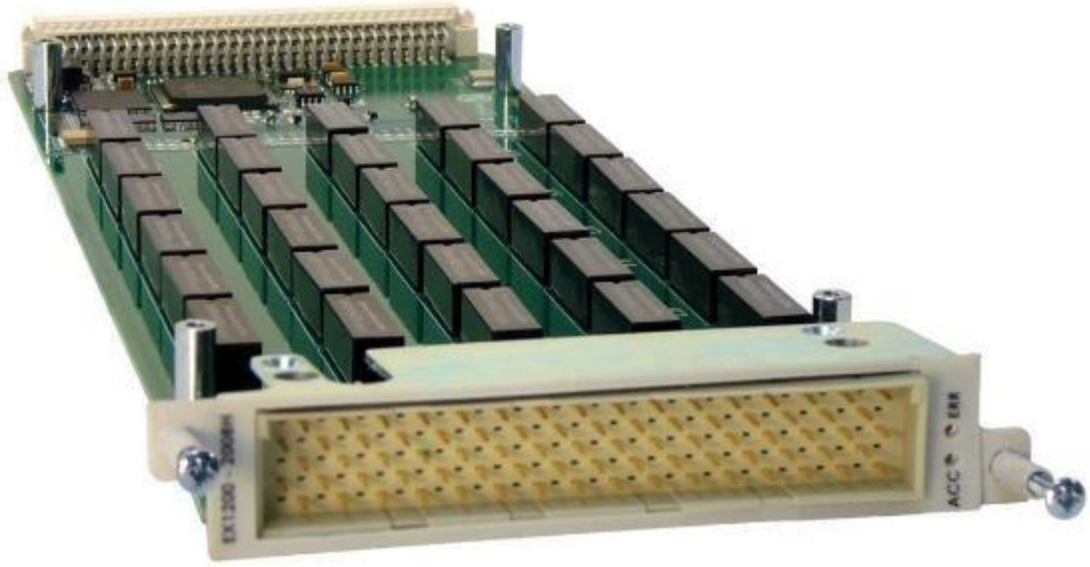


Figure 49. VTI EX1200

- **CMX34**: that is an Integrated PXIe/LXI mainframe with integrated instruments, switching, and all interconnect cabling and connectors assembled, documented and tested, ready to drop in to a test system. This combines the horse-power and data throughput capability of PXIe with the precision switching capability of LXI to deliver best in class system-level performance.

Figure 50. VTI CMX34

- **EX7000 LXI**: that is a mainframe for RF and microwave signal switching and routing. This includes custom RF Interface Units (RFIU) with relays, attenuators, splitters, couplers, isolators, and other microwave or RF components.

Figure 51.l VTI EX7000

4.2. Industrial Shields

Industrial Shields ***[IndustrialShields]*** is an open source product that consists on an Arduino PLC Basic controller that is able to be used in industrial applications. Its main features are:

- Device ready for 12-24 Vdc supply voltage.
- Integrates 16 I/O ports adapted for industrial use as various digital, analogic, PWM and interruption support. They are fully configurable.
- Integrates different interfaces for communication protocols as USB, serial port, RS232, RS485 and I2C communication.
- Support to regulations of industrial reliability. This product is Industrial Automation, Electromagnetic compatibility, ROHS, etcetera.
- The device is programmed using the same Arduino IDE.

Figure 52. Industrial Shields PLC

There exist different versions of the products with different capabilities. Also different accessories can be integrated to the basic version.

4.1. Siemens

Siemens ***[Siemens]*** is one of the most known manufactures of industrial components. As part of its catalogue some industrial PC solutions are available, including its SIMATIC industrial PC products consist on industrial PC specially designed for hard environments. Main characteristics are:

- Rugged enclosures featuring high electromagnetic compatibility (EMC) and degrees of protection up to IP65/NEMA 4.
- Integrated industrial power supplies and redundant power supplies that can be swapped during normal operation.
- Support to wide temperature range.
- High vibration/shock resistance thanks to special hard disk holders.
- Lockable plug connectors and card retainers.

This architecture is available in more than 90 possible configurations.

Figure 53. Siemens SIMATIC possible configurations and options

4.1. Schneider

Schneider ***[Schneider]*** is well-known manufacturer of electric and electronic products. It offers different solutions for automation and control solutions as PLCs and PACs. Some of the most interesting products are:

- **Modicon M580**: that is a Programmable Automation Controller that offers support for redundant processors and Ethernet connectivity.

Figure 54. Schneider Modicom M580

- **Lexium 28**: that is a PLC integrating different AC-servo motors and drives.

Figure 55. Schneider Lexium 28

4.1. FS-Net

FS-net ***[FSNet]*** is a German manufacturer of electronic device production in whose all products meet high quality standards as ISO 9001. One of its main interesting products is:

- **ArmStone A9**: that is a compact Single Board Computer using a PicoITX form factor. It has a Cortex-A9 multi-core processor. The CPU has integrated a Graphic Processor Unit. It has a high capacity of RAM and Flash Memory and it provides a large set of communication interfaces as CAN, PCIe, SATA, etcetera. It is able to work with different voltage ranges as 8 – 14V. Its price is towards 300 euros. Also, the company offers to customize the boards (including an ADC or other interfaces) if the production is more than 300 units.

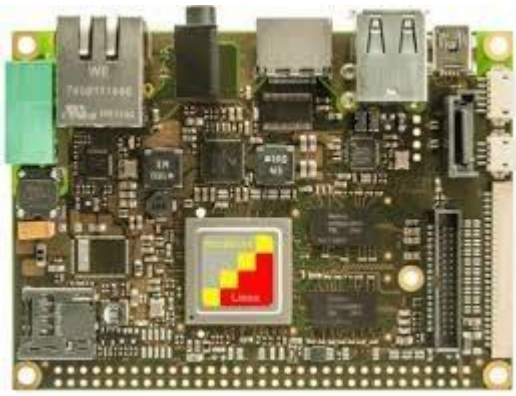


Figure 56. FS-Net ArmStone A9

4.1. Technologic Systems

Technologic Systems ***[TechnologicSystems]*** is a manufacturer with more than 30 years of expertise in the design and development of different single board computers, computer-onmodules and other peripherals for embedded projects. It is specialized in ARM and X86 computer architectures. One of its most powerful peripherals:

- **TS-7250-V2**: that is a Single Board Computer based on the Marvell PXA166 ARM processor at 800MHz/1.GHZ. It provides a great balance between performance and low cost. An extra feature is that the enterprise allows to customize the boards and it is possible to integrate a FPGA. It can work with a power supply voltages from 5V to 28V and it provides an integrated 8 channel 12-bit ADC in which analog input can vary from -10V to 10V.

Figure 57. TS-7250 V2

- **TS-7800**: that is a RoHS compliant Single Board Computer base don Marvel MV88F5182 500MHz ARM9 CPU with 128MB RAM memory and 512MB of Flash memory. It provides Ethernet, dual SATA and USB interfaces and it is supplied with an on-board 12000 LUT FPGA and 110 GPIO lines and other serial ports. The default TS-7800 FPGA load provides a standard PC/104 bus on the 104-pin.

Figure 58. Technologic Systems TS 7800

4.1. Technology in Quality

Technology in Quality ***[TQGroup]*** is a manufacturer with more than 20 years of expertise providing all kind of services related to electronic systems for embedded and Industrial applications based on different architectures. One of its most interesting products is:

- **SBCa335x**: that is a Single Board Computer based on the ARM Cortex – A8 core at 800MHz (in particular the AM3352 made by Texas Instruments). Its main advantage is that it provides a wide range of standard interfaces and also can be extended with additional boards. It supports different operating systems as Linux or QNX. Also it integrates a 6 channel ADC of 12-bit resolution.

Figure 59. TQ SBCa335x

4.1. Digi

Digi ***[Digi]*** is a manufacturer of electronic peripherals formed in 1985. It has a lot of recognised products for building critical communication infrasctructures and embedded systems using System on Modules and Single Board Computers solutions. Remarkable products inside their catalogue are:

- **BL2100 series**: that is a low consumption Single Board Computer equipped with a processor up to 22MHz. It is specially designed for I/O control an monitoring, providing 40 digital I/O pins, 3 RS-232/485 serial ports and a 4 channels ADC of 12bit of resolution.in a compact 4.14" x 3.41" (105 mm x 87 mm). Also several communications interfaces are available.
- **BL4200 series**: that is an evolution of the previos BL2100 series equipped with a more powerful processor (up to 70MHz).

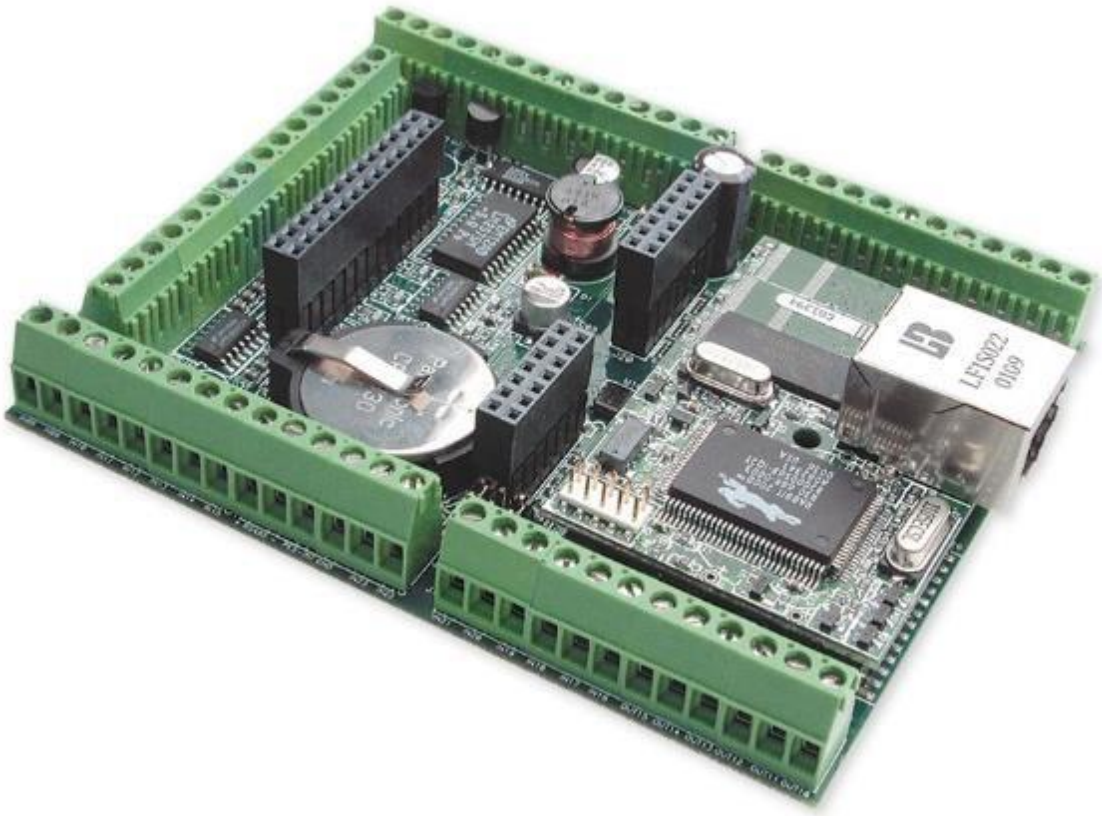


Figure 60. BL2100 series

4.1. ForLinx

ForLinx ***[ForLinx]*** is a Chinese manufacturer founded in 2007 and it is the largest and leading manufacturer of embedded ARM development platforms in North China. Dedicated to providing customers with ARM based embedded products and solutions, its main products are single board computer, CPU module, TFT LCD module and other added-on modules sold to all over the world. One of it most interesting products is:

- **OK335xD-I**: is a stable industrial development platform that integrates a Texas Instruments AM335x processor up to 1GHz. It operates from -40ºC to +85ºC temperature ranges and it provides different interface options as CAN, PROFIBUS, RS-485 or Ethernet. Also it provides digital I/O pins for connecting and using industrial peripherals and devices, including Analog/Digital Converters.

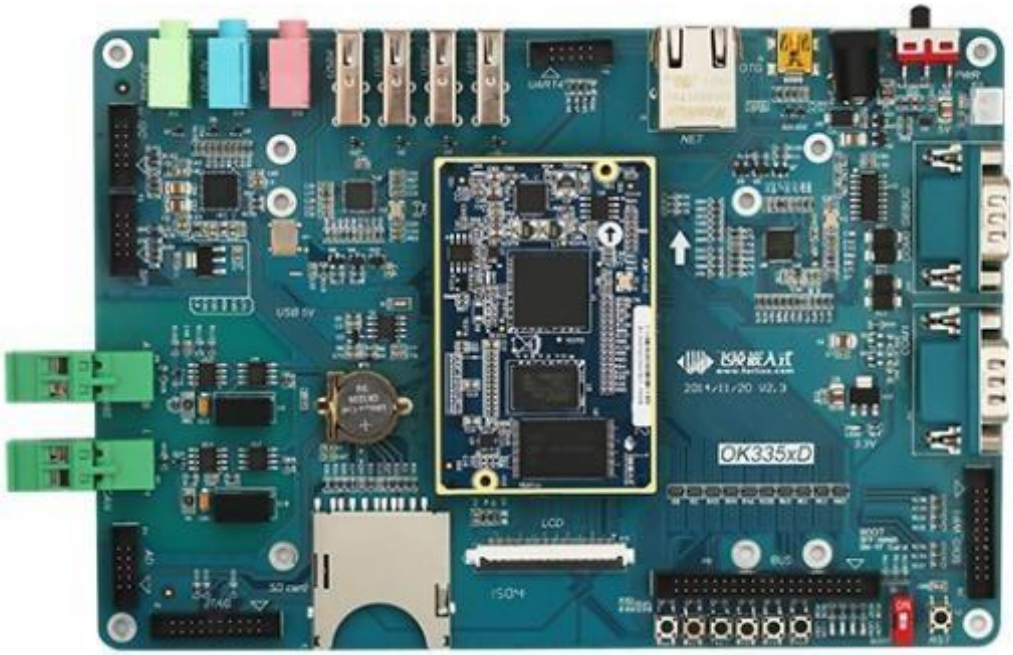


Figure 61. ForLinx SBC 335x D-I

4.1. MPL

MPL ***[MPL]*** is a Swiss company founded in 1985 becoming a reference manufacturer of low power, rugged and embedded systems with extreme working temperature constraints for their use in harsh industrial and military/aerospace environments. One of its most remarkable product is:

- VCMA9: that is a Computer on Module based on ARM920T processor integrated in a small form factor board. It offers Ethernet, CAN and ADC for industrial uses. It has the ability to be operated under extreme conditions without need of fans.

Figure 62. MPL VCMA9

4.1. Myirtech

Myirtech ***[Myirtech]*** is a global provider of ARM hardware and it designs solutions for embedded applications, selling products ranging from board level as development boards, single board computers and CPU modules. Its products are used in industrial control, medical devices and consumer electronics. One of its most remarkable product is:

- **Rico Board**: that is a high-performance Single Board Computer that integrates a Texas Instruments AM437x processor up to 1GHz and integrating a GPU for 3D graphics acceleration. It has interfaces for 4 SPI, 2 dual cameras and 2 independent eight-channel ADC.

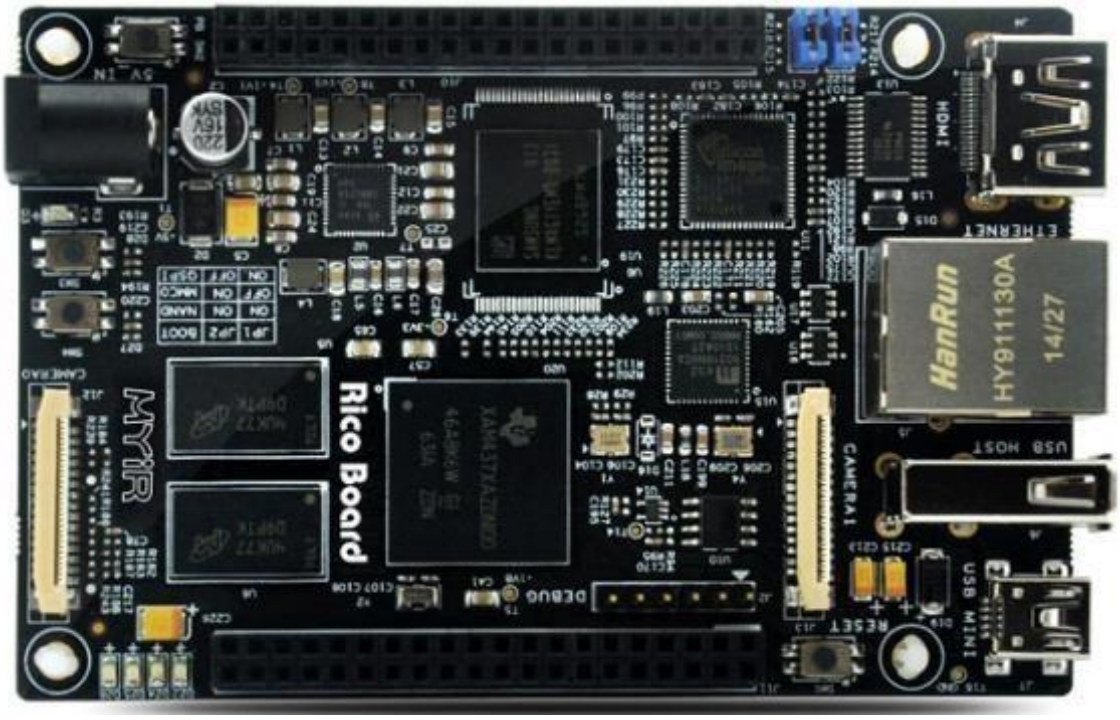


Figure 63. Myirtech Rico Board

4.1. Icoptech

Icoptech ***[Icoptech]*** is a global manufacturer of industrial embedded computers and controllers that distribute its products around the world. An example of its products is:

- SOM-VEX: that is System on a Chip computer based on Vortex86EX processor up to 400MHz. It integrates a 128MB DDR3 RAM onboard and Ethernet interface. It has support for a programmable I/O with 80 pins (up to 10 ports) and a 8 channel ADC with 11-bit resolution. It can operate from -40ºC to +85ºC.

Figure 64. Icoptech SOM VEX

4.1. EuroTech

EuroTech ***[EuroTech]*** is a global company that operates in Europe, North America and Japan. It is focused on the embedded computers filed, in particular, to provide real-time and accurate and reliable computers. Also it provides interconnected devices. One of its best products is:

- **Catalyst EC**: that is a Single Board Computer based on the Intel Atom processor that generates very low heat. It is designed over an EPIC form factor. It integrates an Intel Atom Z5xx processor up to 1.6GHz and 1GB of DDR-2 RAM. Also it provides 16 GPIOs and two configurable RS-232 and RS-422 ports. Finally it supports Windows Embedded Standardd and CE, Windows, Linux and other Real Time operating systems.

Figure 65. Eurotech Catalyst EC

- **Catalyst Module XL**: that is the same device as the *Catalyst EC* but in this case is provided in a rugged edition for high performance in low power, extended temperature applications.

Figure 66. Eurotech Catalyst XL

4.1. Embedian

Embedian ***[Embedian]*** is a manufacturer that provides small computers-on-module and single board computers with support for the most common operating systems. One of the most remarkable products is:

- XPC-8310: is a Single Board Computer equipped with the Marvel XScale PXA320 processor up to 800MHz. The device has a low power consumption and uses a 3.5" standard form factor. It offers audio/video units and interfaces. Also it provices 10/100 Mbps and USB interfaces. The unit can be power supplied from 9V to 36V and it integrates a 4x10 bits ADC imputs.

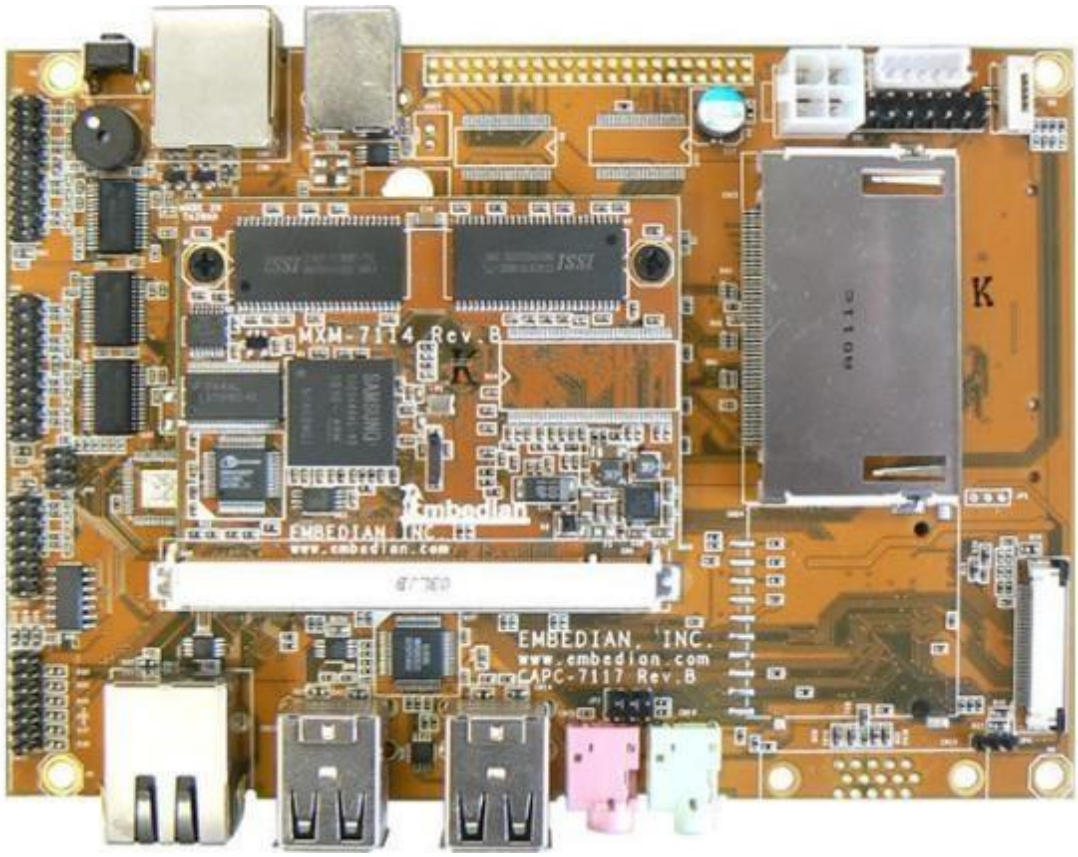


Figure 67. Embedian XPC 8310

4.1. SysLogic

SysLogic ***[SysLogic]*** is a German company that supplies embedded PC's and Single Board Computers for industrial purposes, in particular to be used in automotive engineering, traffic and train technology. One of its most remarkable product is:

- IPCNet SBC-41: that is a Single Board Computer equipped with an aMD Vortex86DX2 processor up to 800MHz with 1GB of DRAM. It integrates two Gigabit Ethernet ports and two USB 2.0 ports. For industrial purposes, it integrates 4xRS232, 2x485 and 2xCAN interfaces. The system can be power supplied up to 24VDC.

Figure 68. SysLogic IPC NET SBC-41

4.1. Lanner

Lanner ***[Lanner]*** is a hardware provider of network appliances and rugged industrial computers. It produces devices as:

- **VES-310 V2**: that is a Single Board Computer that integrates a Atom processor up to 1.66GHz. It operates at 100% capacity with temperatures going from 0º to 60º Celsius. Other features include extensive I/O ports and interfaces for Compact Flash and HDD support. The board can be power supplied up to 12V.

Figure 69. Lanner VES 310 – V2

4.1. Seco

Seco ***[Seco]*** is a hardware manufacturer that offers products for their applications in different sectors, ranging from industrial automation to the medicine, automotive and transport fields. One of its most remarkable products is:

- **SBC a44**: that is a Single Board Computer specifically designed for harsh environments and critical applications. It features an Intel® Atom E3845, Quad Core up to 1.91GHz allowing up to 8GB of RAM memory.

Figure 70. Seco SBC A44

4.1. Libelium

Libelium ***[Libelium]*** designs and manufactures hardware with their correspondent development kits for fast implantation of wireless sensor networks for IoT or M2M applications. One of its most remarkable products is:

- **Waspmote**: that is an Arduino style board that is specially designed to be extremely low consumption. Its main advantage is that the company offers a wide range of expansion shields attached to the board to bring different types of sensors and/or communication interfaces. The simple board is based on ATmega 1281 processor up to 14MHz with 8KB of SRAM memory and 128KB Flash.

Figure 71. Libelium Waspmote

4.1. Abaco

Abaco ***[Abaco]*** is a global manufacturer leader in open architecture rugged embedded systems. It focus its products and solutions for the high profile military/aerospace sea, land and air programs, as well as in commercial and industrial organizations in which rugged reliability is mission-critical. One of its most remarkable products is:

- **SBC326 3U OpenVPX Single Board Computer**: that is a rugged Single Board Computer that integrates an Intel Core i7 quad Core processor supporting up to 16GB. It provides interfaces for 3 Gbit Ethernet, HDMI, SATA, various several ports and up to 8 PCIe slots and 6 GPIOS for expanding the computer capabilities. The device is available in five different levels of ruggedization. (https://www.abaco.com/products/sbc326-3u-openvpx-single-board-computer)

Figure 72. Abaco Systems SBC 326 3U

4.1. Aitech

Aitech ***[Aitech]*** is a global provider of rugged commercial and military embedded computing solutions, including notorious high-profile projects as defense industry and space programs. One of its remarkable products is:

- **S950 3U**: that is a rugged CompactPCI board designed to operate in space radiation environment. It provides a PowerPC 750 processor with 128MB of SDRam and 64MB of Flash Memory. Also it supports Ethernet and serial port interfaces (http://www.rugged.com/s950-3u-compactpci-radiation-tolerant-powerpc%C2%AEsbc)

.

Figure 73. Aitech S950 3U

4.1. Curtiss-Wright

Curtiss-Wright ***[CurtisWright]*** has a business segment named Curtiss-Wright Defense solutions that acts as supplier of highly engineered commercial and system-level products specially designed for deployment in the harsh environments (typically in aerospace, defense and industrial applications) being recognized as one of the most innovative designers and manufacturers of rugged solutions. One example of its products is:

- **VPX3-1259**: is a high performance Single Board Computer that integrates a Intel Core i7 processor with 16GB of RAM memory. The board has a math extension coprocessor to accelerate math-intensive algorithms. Also it integrates a GPU Open GPL compatible for enhance graphic applications. Interfaces as PCIe, SATA, USB and other serial ports are provided (https://www.curtisswrightds.com/products/cotsboards/processor-cards/3u-intel-sbc/vpx3-1259.html)

.

Figure 74. Curtiss Wrigth VPX3 1259

4.1. Emac

Emac ***[Emac]*** designs, manufactures and distributes Single Board Computers and other industrial equipment specially designed for the embedded marketplace since 1985. Additionally it offers driver development and software application programming for its products.

- **SBC 0300**: is a 2.5" Single Board Computer base don the Pico-ITX specification. It feautres an ARM CortexTM-A8 up to 800 MHz with 2GB. It provides 5 USB interfaces, LAN, Audio, GPIOs and HDMI interfaces. Additionaly 3 serial ports, SPI, I2C and 26x GPIOs are included. The board can opérate from -40º to 85ºC (http://www.emacinc.com/products/pc_compatible_sbcs/SBC-0300).

Figure 75. EMAC SBC 0300

4.1. Orion Technologies

Orion Technologies ***[OrionTechnologies]*** is a manufacturer specialized in Single Board Computers design and development for over 20 years. The majority of its products are offered in four levels of ruggedization from standard commercial to rugged, extended temperature with conduction cooling for embedded solutions. One of its most notable products is:

- **VPX 7664**: that is a Single Board Computer that integrates an Intel Core i7 with up to 16GB of RAM memory. It features few PCIe slots for its expansion. For connectivity it provides two 10Gbe Ethernet ports, four serial ports and six USB ports. The board provides a rugged design and extended temperature operation (http://www.oriontechnologies.com/products/processors/vpx-processor/vpx7664/)

Figure 76. Orion Technologies VPX 7664

4.1. Extreme Engineering Solutions

Extreme Engineering Solutions ***[XES]*** is a manufacturer is an enterprise specialized in the design of hardware and software solutions for the embedded systems market varying from high-performance single board computers, ruggedized extended temperature systems and telecommunication modules. One of its most remarkable products is:

- **Xpedite 7575**: that is a single board computer base don the Intel Core i7 with 16GB of RAM memory. It provides three Gigabit Ethernet. It hosts numerous I/O ports, including PCI Express, USB, SATA, graphics and RS-232/422/485. Also it provides driver support for VxWorks, Linux and Windows operating systems (http://www.xesinc.com/products/sbcs/xpedite7575/).

Figure 77. XES Xpedite 7575

4.1. Mercury Systems

Mercury Systems ***[MercurySystems]*** is a manufacturer specialized in the design of defense industrial electronics that includes single board computers. One of its most remakarable product is:

- **VX6200CC**: that is a rugged Single Board Computer featuring two dual-core Intel Xeon Processors up to 1.66GHz with 4Gb of RAM memory. In integrates two USB ports, two RS-232 serial ports, SATA, GPIO and PCIe slots. Dual processor, dual memory configuration. The board can operate from -40º to 71º and can resist shocks until 80G during 11ms and vibrations varyinf from 0.1g2/Hz at 5-2000Hz durint 1h. Other interesting features is that it can operate from 0 to 70000 feet and also it can be stored until 100000 feet. Finally the board meets the standard UL1950/60950 (https://mrcy.com/products/boards/vx6_200cc_dual_dual_core_xeon_vxs/).

Figure 78. Mercury Systems VX 6200 CC

6. Prototyping Hardware architectures

Instead of using industrial hardware we can choose for alternative options as small computers or microcontrollers for prototyping. They can be used to develop test platforms or first designs before their real implantation in the final system or environment. Currently we can find a wide range of popular hardware based on the concepts of reference architectures as Arduino or Raspberry Pi.

Next section we summarize the main characteristics of this hardware.

4.2. Arduino

Arduino ***[Arduino]*** is an open source hardware platform based on a simple board that integrates a microcontroller and few input/output interfaces. It has his own development language and tools and it suits perfect for his use in multidisciplinary electronic projects. The basic approach consists on a small board that integrates a cheaper 8 bit microcontroller, although newer versions adopt powerful 32 bit microcontroller. All versions are complatible at development level in the basic features (using the same language and libraries)

In next sections we describe the most representative versions of this architecture.

4.2.1. Arduino UNO

Figure 79. Arduino UNO

Main features:

- Atmel ATmega320 de 8 bits a 16MHz microcontroller at 5V.
- 32KB Flash memory (0.5KB reserved for bootloader).
- 2KB SRAM.
- 1KB EEPROM.
- Output pins can work until 20V output voltage.
- 14 digital pins, 6 can be used as PWM.
- 6 analogic pins until 40mA output current.

4.2.2. Arduino TRE

Ilustración Figure 80. Arduino TRE1. Arduino TRE

Main features:

- Texas Instrument Sitara AM335x microcontroller up to 1GHz with ARM Cortex A8
  - 512MB DDR3L memory.
- 32KB Flash memory.
- 2.5KB SRAM memory.
- 1KB EEPROM memory.
- 14 digital pins, 7 can be used as PWM.
- 6 analogic pins.
- Integrates HDMI, USB, microSD and other interfaces.

4.2.3. Arduino ZERO

Figure 81. Arduino Zero

Main features:

- Atmel SAMD21 MCU microcontroller up to 48Mhz with ARM Cortex M0 32 bits.

- 256KB Flash memory.
- 32KB SRAM memory.
- 16KB EEPROM memory.
- Works between 3v3 and 5v current voltage (7mA).
- 14 digital pins, 12 can be used as PWM or UART.
- 6 analogic pins.

4.2.4. Arduino LEONARDO

Ilustración Figure 82. Arduino Leonardo2. Arduino Leornado

Main features:

- ATmega32u4 microcontroller up to 16MHz.
- 32KB Flash Memory (4KB reserved for bootloader).
- 2.5KB SRAM memory.
- 1KB EEPROM memory.
- 20 digital pins, 7 can be used as PWM.
- 12 analogic pins.
- mini-USB port.

4.2.5. Arduino YUN

Ilustración Figure 83. Arduino YUN3. Arduino Yun

Main features:

- ATmega32u4 microcontroller up to 16MHz.

- Includes WiFI network interface Atheros AR9331.
- 32KB Flash memory (4KB reserved for bootloader).
- 2.5KB SRAM memory.
- 1KB EEPROM memory.
- 20 digital pins, 7 can be used as PWM.
- 12 analogic pins.
- mini-USB port..
- It works with chip AR9331 up to 400MHz that can include an embedded Linux system.

4.2.6. Arduino DUE

Ilustración Figure 84. Arduino DUE4. Arduino DUE

Main features:

- Atmel SAM3X8E ARM Cortex-M3 32 bits microcontroller up to 84MHZ (3,3v).
- 96KB Flash memory.
- 512KB SRAM memory.
- 54 digital pins, 12 can be used as PWM.
- Current up to 130-800mA (3v3 and 5v).
- 12 analogic pins, 4 UARTs.
- USB, 2 DAC, SPI, JTAG interfaces.

4.2.7. Arduino MEGA

Ilustración Figure 85. Arduino MEGA5. Arduino Mega

Main features:

- ATmega2560 8 bits microcontroller up to 16MHz at 5v voltage current.
- 256KB Flash memory (8KB reserved for bootloader).
- 8KB SRAM memory.
- 4KB EEPROM memory.
- 54 digital pins, 15 can be used as PWM.
- 16 analogic pins.

4.2.8. Arduino ETHERNET

Ilustración Figure 86. Arduino Ethernet6. Arduino Ethernet

Main features:

- ATMega328 microcontroller up to 16MHz.
- 32KB Flash memory.
- 2KB SRAM memory.
- 1KB EEPROM memory.
- 14 digital pins, 4 can be used as PWM.
- 6 analogic pins.

4.2.9. Arduino FIO

IlustFigure ración 87. Arduino FIO7. Arduino FIO

Main features:

- ATmega328p microcontroller up to 8MHz.
- 32KB Flash memory.
- 2KB SRAM memory.
- 1KB EEPROM memory.
- 14 digital pins, 6 can be used as PWM.
- 8 analogic pins.

4.2.10. Arduino NANO

Ilustración Figure 88. Arduino NANO8. Arduino NANO

Main features:

- ATmega168 microcontroller up to 16MHz.
- Reduced size: 18,5 × 43.2mm.
- 16KB Flash memory.
- 1KB SRAM memory.
- 512B EEPROM memory.
- 14 digital pins, 6 can be used as PWM.
- 8 analogic pins.

4.2.11. Arduino LILYPAD

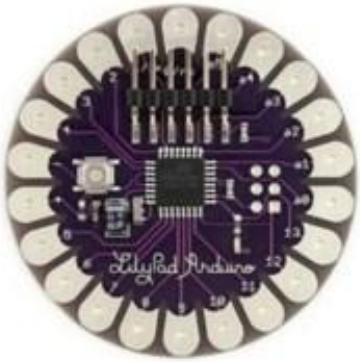


Ilustración Figure 89. Arduino LilyPAD9. Arduino LilyPad

Main features:

- ATmega328V microcontroller up to 16MHz at 5.5V current voltage.
- 16KB Flash memory.
- 1KB SRAM memory.
- 512B EEPROM memory.

- 14 digital pins, 6 can be used as PWM. 6 analogic pins.

4.2.12. Arduino PRO

Figure 90. Arduino PRO

Main features:

- ATmega328 microcontroller up to 16MHz at 5V voltage current.
- 32KB Flash memory.
- 1KB SRAM memory.
- 512B EEPROM memory.
- 14 digital pins, 6 can be used as PWM.
- 6 analogic pins.

4.2.13. Arduino ESPLORA

Ilustración Figure 9110. Arduino Esplora. Arduino Esplora

Main features:

- ATmega32u4 microcontroller up to 16MHz at 5V voltage current.
- 32KB Flash memory (4KB reserved for bootloader).
- 2.5KB SRAM memory.
- 512B EEPROM memory.

4.2.14. Arduino MICRO

Figure 92. Arduino Micro

Main features:

- ATmega32u4 microcontroller up to 16MHz.
- 32KB Flash memory.
- 2KB SRAM memory.
- 1KB EEPROM memory.
- 20 digital pins, 7 can be used as PWM.
- 12 analogic pins.

4.2.15. Arduino BT

Figure 93. Arduino BT

Main features:

- ATmega328 microcontroller up to 16MHz.
- Bluetooth interface integrated.

4.2.16. Arduino Shields

Shields are expansion modules that allow to add new functionalities and capacities to the Arduino boards. Usually, these components are used to expand the board with communication interfaces or to add new sensors or actuators. There exist a wide range of elements of this type available on the market. Next we list a brief summary of some of them:

- **4x4 Driver Shield:** this shield integrates 16 MOSFET controllers to manage current voltages until 30VDC in order to use 4 engines by shield. Integrates a SPI bus interface compatible with ShiftPWM programming library. (http://www.logoselectro.com/store/4x4-driver-shield)

- **Adafruit GPS & Datalogging Shield:** this shield integrates a GPS transceiver that is able to save the data measures to a flash memory card.
- **Adafruit Wave Shield:** this shield can play audio files up to 22 kHz stored in a SD memory card. The shield is able to access directly to the files.
- **Adafruit XPort/Ethernet Shield:** this shield integrates a XPort Ethernet enabling internet connection to the board. (http://www.ladyada.net/make/eshield/)
- **Annikken Andee:** advance shield that allows to connect a smartphone for monitor and control the board by means of the Bluetooth protocol. (http://www.annikken.com/)
- **Battery Shield:** it allows to connect a USB rechargeable battery to power supply the board up to 28 hours. (http://www.liquidware.com/)
- **ButtonShield:** shield that integrates a panel with a keypad. (http://antipastohw.blogspot.com.es/2009/06/live-footage-of-buttonshield-inwild.html)
- **Cosmo GSM Connect:** that shield integrates a GSM module to enable M2M communications. It implements de TCP/IP stack. (http://jt5.ru/shields/cosmo-gsm/)
- **Cosmo USB Host:** shield that enables a USB host interface (http://jt5.ru/shields/usbhost/).
- **Cosmo WiFi Connect**: shield that integrates a WiFi 802.11 b/g interface. (http://jt5.ru/shields/cosmo-wifi/)
- **Critical Velocity LCD Shield:** shield that enables an interface to connect a LCD display to the board. (http://www.criticalvelocity.com/item.php?itemid=shield9)
- **FabScan-Shield:** shield used to build 3D scanners. (https://github.com/watterott/FabScan-Shield)
- **HacroCam VGA Camera Shield:** shield that integrates a VGA camera. It transfers the images by using the I2C bus.
- **IR Remote Shield 1v09 and IR Remote Shield 2v14J:** multi-purpose shield that integrates different peripherals and interfaces. (http://krazatchu.ca/2014/01/17/irr3m0c0n-1v09-multi-purpose-arduino-shield-with-ir/)
- **MEGA Battery Pack:** shield for the Arduino Mega that provides a lithium battery up to 27 hours. It is rechargeable by means of the USB port. (http://www.liquidware.com/shop/show/BPM/Mega+Backpack)
- **mSD-Shield:** shield that enables a microSD card reader and a 2,8" display (MI0283QT: 240x320 16bit color). (https://github.com/watterott/mSD-Shield)
- **Open-Electronics.org WiFi Shield:** shield that integrates a WiFi interface using the MRF24WB0MA microchip. (http://www.open-electronics.org/arduino-wifi-shield/)
- **Phi-2 Shield:** shield that integrates different interfaces and peripherals as LCD display, buttons, DS1307 Real-time clock, GPS connector, etcetera. (https://liudr.wordpress.com/shields/phi-2-shield/)
- **PlainDSP Audio Kit:** audio-process kit that integrates a different input/output connectors. (http://www.plaindsp.com/product/audio-kit/)
- **Rugged Circuits Gadget Shield:** multipurpose shield that integrates a 3-axis accelerometer, InfraRed emissor, buttons, etcetera. (http://www.ruggedcircuits.com/html/gadget_shield.html)
- **SMARTGPU TFT LCD Shield-SMARTGPU:** shield that integrates a graphic processor. (http://www.vizictechnologies.com/#/development/4554296549)
- **Tune MP3 Decoder:** shield that is able to decode the MP3 protocol for music playing. (http://snootlab.com/shields-snootlab/815-.html)

- **Z-WeatherShield**: shield that integrates different weather measuring sensors. (http://tinkr.de/blog/arduino-weather-shield-schematics-layout-code-everything-youneed/)

4.2.17. Sensors

The Arduino platform provides a wide range of sensors for their integration with the board via the digital/analogic pins. We can easily find next king of sensors:

- Accelerometers and gyroscopes.
- Switches.
- Cameras and video-recorders.
- Presence and distance detector sensors.
- Movement sensors.
- Current and voltage sensors.
- Environmental parameters sensors.
- Rotation sensors. Sound sensors.
- Pressure sensors. Etcetera.

For more information we can get an exhaustive sensor list at: http://www.trossenrobotics.com/c/arduino-sensors.aspx

4.2.18. Engines

The Arduino platform has a lot of available engines as:

- **DC engines**: DC engines for Arduino must use an external driver that can be able to provide more current that the board can supply (40mA).
- **Servo-engines**: although they are similar to DC engines, they have the capacity to be in a determinate position established in the 0 t o180 degrees angle.
- **Stepper engine**: It is an electromagnetic device that converts electric impulses to mechanical movements.

4.3. Intel Galileo

Figure 94. Intel Galileo

Intel Galileo ***[IntelGalileo]*** is a microcontroller that integrates an Intel® Quark SoC X1000 32 bit processor up to 400MHz that is the equivalent to Intel Pentium processor with smaller size. Its main characteristic is its low power consumption and its compatibility with Arduino Shields. Also, the microcontroller integrates different interfaces as PCI Express, ACPI, Ethernet 10/100Mb, USB 2.0, UART, RS-232, JTAG and RS-232. Finally it has available 13 digital pins and 5 analogic pins.

4.4. Intel Edison

Figure 95. Intel Edison

Intel Edison ***[IntelEdison]*** is a complete personal computer with the size of SD Card (32x24x2.1 mm). It has a SoC Quark 32 bits processor up to 400MHz. Also it integrates a 4GB RAM with the support to Bluetooth LTE and WIFI interfaces. It has available 20 digital pins (4 can act as PWM) and 6 analogic pins. Finally it provides UART, I2C, ICSP and micro-USB interfaces.

4.5. Raspberry Pi

Ilustración Figure 9611. Raspberry Pi. Raspberry Pi

Raspberry ***[RaspberryPi]*** includes a complete system-on-chip based on the ARM1176JZFS processor up to 1GHz. Also it integrates a VideoCore IV graphic processor able to play up to 1080p. It has different interfaces as Ethernet, USB, HDMI and minijack. Currently it exists different board revisions for the Raspberry. The most important ones are:

- **Rasbperry Pi 1**: that integrates a 700 MHz single-core ARM1176JZF-S processor.
- **Raspberry Pi 2**: that integrates a 900 MHz quad-core ARM Cortex-A7 processor.
- **Raspberry Pi 3**: that integrates a 1.2 GHz 64-bit quad-core ARM Cortex-A53 processor.
- **Raspberry Pi Zero**: that integrates a 1 GHz ARM1176JZF-S single-core processor.

4.6. Adafruit Trinket

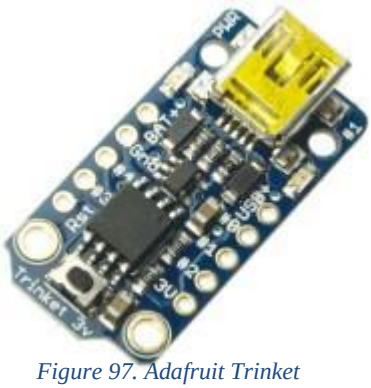


Figure 97. Adafruit Trinket

Adafruit Trinket ***[AdafruitTrinket]*** is a microcontroller with an Atmel ATtiny85 processor with a flash memory of 8KB (2.5KB reserved for bootloader) and 5 digital pins, 3 analogic pins and 2 PWM pins. Although it is not full compatible with Arduino platform it can be programed using the same language and libraries.

4.7. NextThing CHIP

Figure 98. NextThing Chip

NextThing CHIP ***[NextThingCHIP]*** is a cheap microcontroller (it costs 9 dollars) that integrates multiple communication interfaces. His main characteristics are:

- WiFI interface.
- Bluetooth 4.0 interface.
- R8 processor up to 1GHz.
- 512MB RAM memory.
- 4GB of storage.
- HDMI and VGA interfaces.
- USB interface that can be used to supply power the board.

4.8. Odroid

Odroid ***[Odroid]*** are a collection of Single Board Computers for general purpose and prototyping. They have three main products:

- **ODROID-XU4**: that is a Single Board Computer equipped with an Octa Core Processor. It is specially designed to be packed in a small form factor (82x58x22mm including the fan cooler) in an energy-efficient hardware. It has USB 3.0 and Gigabit Ethernet interfaces, supporting Linux or Android operating systems.

Figure 99. Odroid XU4

- **ODROID-C2**: that is a single board computer integrating a 64-bit cortex-A53 up to 2Ghz processor. It has 2GB of SDRAM and has support form Gigabit Ethernet and eMMC5.0 flash memory. It has 40+7 pin GPIO for connection interfaces to the board. Also it has available 4 USB ports.

Figure 100. Odroid C2

- **ODROID-C1+**: that is a single board computer integrating a quad-core Amlogic processor and a GPU for vide managing. It can be used as general purpose computer or home automation. It integrates 4 USB ports and a Gigabit Ethernet interface.

Figure 101. Odroid C1P

4.9. CubieTech

CubieTech ***[CubieTech]*** is a manufacturer of open-source hardware that offers different Single Board Computers and mini-PCs. Inside its catalogue the most interesting products are:

- **Cubieboard5 or CubieTruck**: that is an open source hardware equipped with an ARM Cortex A7 Octa-Core and PowerVR SGX544 GPU up to 700MHz supporting OPENGL and OpenCL. It has 2GB of DDR3 RAM memory. It integrates Ethernet, WiFI and Bluetooth communication interfaces integrated using microSD cards as permanent storage. Also 2 USB, SPDIF, Infrared and jack interfaces are provided. Extended pins include I2S, I2C, SPI, CVBS output, Low resolution ADC, UART, 2x PWM. Its operation range is from -20º to 70º. It has a board size of 112m*82mm*18mm.

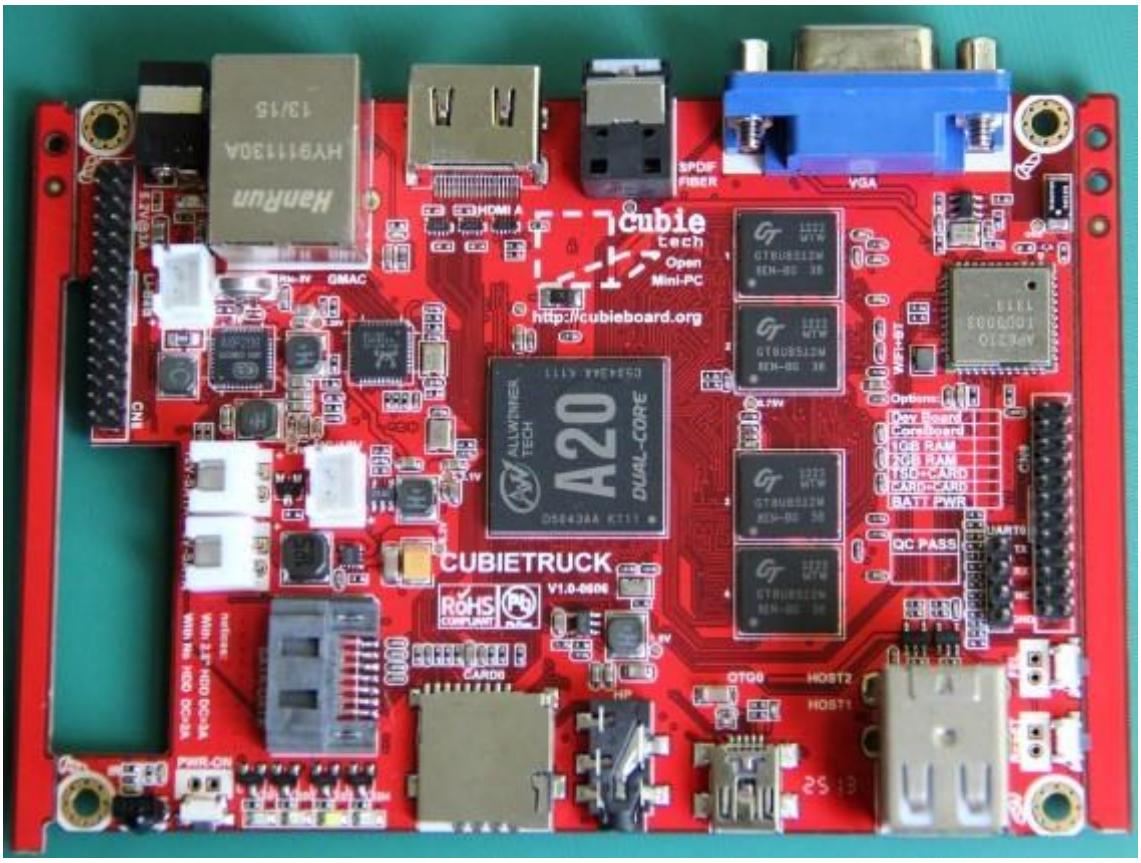


Figure 102. Cubieboard Truck

- **Cubietruck-plus-metal**: that is a packed version of the Cubieboard5 inside a metal chassis ready to be used. The chassis size is 170mm*125mm*100mm.

Figure 103. Cubietruck puls metal chassis

4.10. Beaglebone

Beaglebone ***[Beaglebone]*** is a manufacturer that offers cheap high-performance single board computers able to run any Linux operating system. It offers different products as:

- **Seedstudio BeagleBone Green**: that is equipped with an ARM3358 ARM Cortex-A8 processor up to 1GHz. It enables 7 analog and 65 digital pins. It has integrated 512MB of DDR3 RAM memory. Also it provides USB 2.0, UART, 8 PWM, pins LCD, GPMC, MMC1, 2 SPI, 2 I2C, A/D Converter and 2 CAN Bus interfaces.

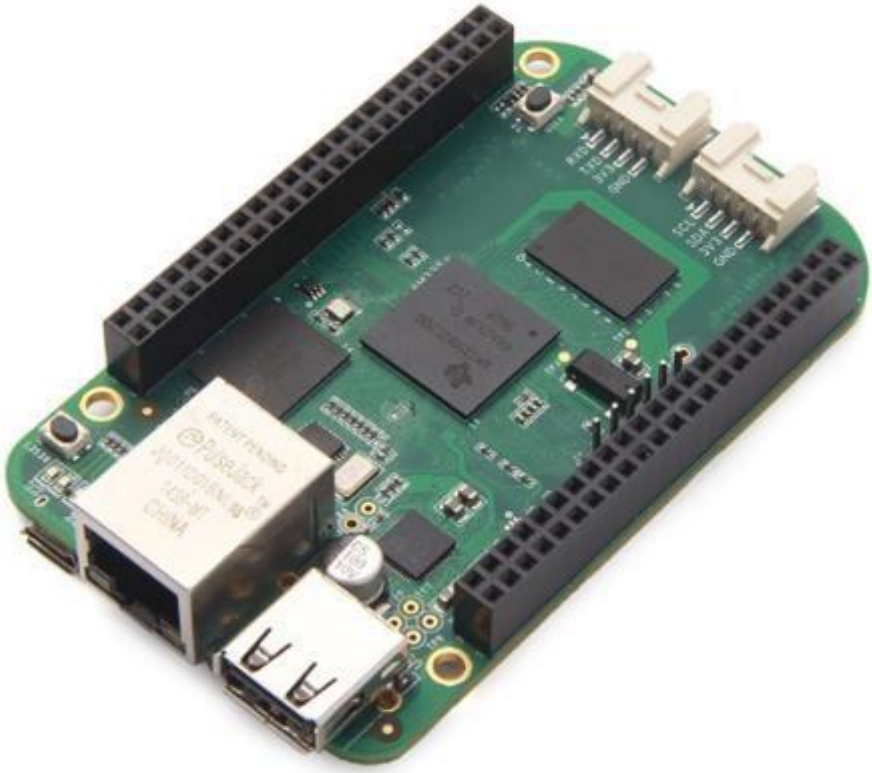


Figure 104. BeagleBone Green

- **SeedStudio BeagleBone Black**: that is equivalent to the Green board but integrating a microHDMI interface.

Figure 105. Beaglebone black

- **BeagleBoard xM**: that is equipped with an ARM3730 ARM Cortex-A8 processor up to 1GHZ. It has the same features of the basic boards adding more interfaces as DVID, S-Video, JTAG, camera, etcetera interfaces.

Figure 106. Beagleboard xM

4.11. SeedStudio

SeedStudio ***[SeedStudio]*** is a provider of diverse electronic equipment. Also it produces its own electronic devices, boards and appliances that in the majority of cases follow the Arduino and other open hardware specifications. One of the most interesting boards is the Seed Tiny BLE. This board is specially designed for low energy consumption in small size form integrating a Bluetooth Low Energy interface. It has a 32-bit ARM Cortex-M0 processor up to 16 MHz and it is provided with accelerometers and gyroscope sensors. It has a 4 I/O that can be used as analog or digital input/output. Also I2C, SPI and UART interfaces are provided. It is packed in a 43.3mm x 29.0 mm x 4.3 mm size board. As additional improvement it is integrated with current measurement sensor to provide real time energy consumption data in order to optimize the software design.

Figure 107. Seedstudio Tiny BLE

4.1. GizmoSphere

GizmoSphere ***[GizmoSphere]*** is an open source platform consisting on a x86-based Single Board Computer. Its main characteristic is that provides direct Access to a wide range of interfaces, including GPIO, ADC/DAC, PWM, I2C, SPI, USB, SATA, HDMI, mSATA, microSD card slot and PCIe. The processor AMD GX210 up to 1GHz integrates a GPU. The system can be easiliy expanded using additional cards or shields.

Figure 108. Gizmosphere Gizmo 2

7. Additional hardware

Sometines the basic models and specifications of devices do not fulfil the application requirements. In this case, additional hardware could be attached to the processors in order to increase their capabilities and functionalities. Next we show a brief summary of potential hardware that can be used in industrial projects or applications.

4.2. Analogic/Digital Converters (ADC).

An analog-to-digital converter (simply or ADC or A/D) is an electronic device designed to convert continuous physical quantity (voltage or current) to a digital value representing the quantity amplitude. Intrinsically, the conversion process (quantization) introduces a small amount of error depending on its sampling rate. Next we summarize some of ADC boards.

- **Technlogic systems TS-ADC16**: that is a board with 16 channels of 16 bits sampling resolutions with a 2x100ksps (kilo samples per second). Inputs can vary from -10V to 10V. It is mounted over a PC/104 form factor board. Also it integrates 4 digital inputs and 1 digital output. (https://www.embeddedarm.com/products/TS-ADC16 , http://wiki.embeddedarm.com/wiki/TS-ADC16).
- **ARD LTC2499**: that is a pin-compatible board with Arduino platform that provides eight channels with a 16-24 quantization bits. (http://www.iascaled.com/store/ARDLTC2499).

- **ADC Pi:** that is a pin-compatible board with the Arduino platform that provides eight channel until 17 quantization bits. The amount of bits used for quantization can be programmed varying in this case sampling rate. (https://www.abelectronics.co.uk/p/17/ADC-Pi-V2---Raspberry-Pi-Analogue-toDigital-converter).
- **Raspberry Pi AD/DC Converter:** that is a pin-compatible module with Raspberry Pi boards that integrates 8 channel with a 24 quantization bits able to manage 30ksps.(http://www.waveshare.com/high-precision-ad-da-board.htm).
- **Abaco ICS 1640:** that is a powerful PCI interface ADC/DAC board with 16 channels with 24-bit resolution with 2.5MHz of sampling rate (http://buyersguide.mae.pennnet.com/abaco-systems/p/ics1640-adc-pci-express-x417channel-module.html).
- **NI PCI 4461:** that is a PCI board that integrates different channels up to 24-bit resolution and 202ksps of data sampling. Inputs tolare until 42V of input power voltage. (http://sine.ni.com/nips/cds/view/p/lang/en/nid/202236).
- **Xtreme I/O PCI-104:** that is a PCI-104 module integrating 32 channels up to 16-bit resolution up to 10V of input power voltage. (http://www.dpie.com/pc104/analogio/connect-tech-xtreme-io-adc-dac).

8. Operating Systems

For the existent platforms we can find different operating systems that eases the managing and programming of the architectures by means of providing abstractions for the computer resources, interfaces and peripherals. Next we provide a list of some of the most popular operating systems.

4.3. ArdOS

ArdOS ***[ArdOS]*** is a tiny operating systems developed for Arduino microcontrollers as ATMega 168, 328, 1280 and 2560. This operating system aiding to developing multi-task applications. The programming interfaces are available in Processing language. It provides a basic multi-task scheduling based on job priorities that can be useful to develop real-time applications. Also, semaphores and mutex are provided. Finally, a message queue is implanted that can be used to communicate and synchronize the different tasks running. The operating system can be configured to only incorporate the parts needed for the particular board.

4.4. DuinOS

DuniOS ***[DuinOS]*** is an operating system that provides pre-emptive multitasking for applications developed in the Arduino platform. It is an open-source project based on the FreeRTOS specially adapted for the Arduino.

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4.5. FemtoOS

FemtoOS ***[FemtoOS]*** is an operating system optimized for embedded systems. It provides a pre-emptive multitask scheduler for the managing of each different running processes. The resource usage is minimal due to it can be integrated in constrained devices with few fash memory kilobytes using little RAM memory. It works over the most common ATMega microcontrollers including the most Arduino platform ones. It manages up to 16 concurrent

tasks. It has a modular structure that can be add or delete certain components in order to adapt to the resources availability of the system.

4.6. RTuinOS

RTuinOS ***[RTuinOS]*** is an operating especially designed for the Arduino platform. The system is provided as an Arduino library and it offers different primitives for control and communication for pseudo-concurrent processes (due to Arduino microcontrollers does not support real multi-tasking). The scheduler assigns different execution time for the processes using a Round Robin policy for executing these processes.

4.7. Raspbian

Raspbian ***[Raspbian]*** is a Linux distribution specially designed and optimized for Raspberry Pi. It is based on Debian Wheezy Linux and it offers the same basic functionalities and applications as each desktop Linux distribution. It has more than 35000 application packets optimized for the platform, being the most used distribution for the platform.

4.8. Windows 10 IoT Core

Windows 10 IoT Core ***[Windows10IoT]*** is an operating system that offers a complete solution to develop Internet of Things applications. Windows 10 IoT can be installed even in a Raspberry Pi device providing basic interfaces to capture and send data from the devices and later be sent to the server or the cloud. Although there is not a complete flexibility for the programmer in the development of the application, it offers some aids to enhance and agilize the sensor application developing.

4.9. Arch Linux ARM

Arch Linux ARM ***[ARchLinuxARM]*** is a Linux distribution optimized for ARM based computers. The system has as base the Arch Linux distribution. Its main difference with respect to other distributions is its simplicity. System updates include the revision of the whole components of the system, avoiding incompatibilities amongst them.

4.10. TinyOS

TinyOS ***[TinyOS]*** is an operating system specially designed for wireless devices with power consumption constraints. It offers different abstractions for the machine resources as the manage of memories of the system with blocks and sectors. Its main advantage is to provide support for diverse wireless protocols as *802.15.4*, *Zigbee* y *6LoWPAN/RPL*. The scheduler works with a FIFO policy in which running applications have the obligation to return the control of its processes to the system.

4.11. Contiki

Contiki ***[Contiki]*** is an operating system optimized for its implantation on microcontrollers provided with communication interfaces. Its main advantage is that it offers a multitasking scheduler and a complete implementation of the TCP/IP protocol stack (supporting IPv6 and 6LoWPAN) that uses a small amount of memory flash (40KB) a only few bytes of RAM memory (2KB). Inside the system, processes can communicate using messages. Extra features include a visual window manager, web server and light web client.

4.12. LiteOS

LiteOS ***[LiteOS]*** is a free UNIX-based operating system especially designed for its use in wireless sensor networks. Its main advantage is that can work with different communication interfaces simultaneously and allowing the message intercommunication amongst them. It has support to threads and the operating system can be compiled and adapted for working in different platforms as ATmega 128 and ATmega1281.

4.13. BertOS

BertOS ***[BertOS]*** is a free operating system specially designed for embedded systems. It is distributed under GPL license. It offers a modular design that allows its own configuration and optimization depending on the execution environment. For this reason, it can be used from small 8 bits microcontrollers to complex ARM-32 bits architectures. It scheduler supports pre-emptive multitasking and provides different abstractions for process intercommunication as semaphores, signals and mutexes. An additional characteristic is that it offers a hardware abstraction layer of different devices that eases to the programmer the developing of applications. Also it offers support for network protocols including the TCP/IP stack.

4.14. NetBSD

NetBSD ***[NetBSD]*** is an open source Unix-lie operating system. It is based on the Berkeley Software Distribution (BSD). Its main characteristics focuses on code clarity, careful design, and portability across many computer architectures, and it is common to be used for embedded systems (supporting a large number of 32 and 64 bit architectures). Also it has a non-restrictive use and distribution license. Portability is achieved by the use of a lowlevel hardware abstraction layer interface. This allows a particular device driver to work without modification for different architectures, only modifying the dependant architecture parts of the code taking much less time to port to new hardware. This platform independence aids the development of embedded systems, particularly, when the entire toolchain of compilers, assemblers, linkers, and other tools fully support cross-compiling. Another remarkable features of NetBSD are:

- **Portable build framework**: that lets a developer to build a complete system for any architecture from a different architecture (cross-compiling). This is particular important for embedded systems due that using NetBSD is not required extra additional development of software or other tool than the toolchain and target rehost.
- **Package library**: that are available more than 15000 packages that can be compiled for any architecture.
- **Symmetric multiprocessing**.
- **Security**: providing various security features from the kernel to the network communications.
- **Virtualization**: by means of the Xen virtual-machine.
- **Storage facilities**: that allow compatibility with wide range of file systems.

4.15. MicroC/OS-II OS-III

MicroCOSII ***[MicroCOSII]*** or Microcontroller OS is a portable operating system specially designed for microcontrollers and embedded systems. It can be stored over a ROM memory, it is fully scalable and uses a pre-emptive real-time deterministic multitasking kernel. It is written in complete 100% ANSI C source code and it is available for a largest number of architectures. Its more remarkable features are:

- Pre-emptive multi-tasking.
- Support to semaphores; event flags; mutual-exclusion semaphores that eliminate unbounded priority inversions; message mailboxes and queues; task, time and timer management; and fixed sized memory block management.
- Certified for safety-critical applications as Avionics DO-178B, Medical FDA premarket notification (510(k)) and pre-market approval (PMA) devices SIL3/SIL4 IEC for transportation and nuclear systems. Compliant with the Motor Industry Software Reliability Association (MISRA-C:1998) C Coding Standards.

4.16. QNX

QNX ***[QNX]*** is a commercial Unix-like real-time operating system specially designed for embedded systems. It is widely deploy over mobile phones, cars and other appliances. Its design architecture differs from the more traditional perspective of kernel due to kernel is composed by small tasks (or servers) allowing to enabling or disabling the demanded feature without changing or recompiling the operating systems. Also it allows having small size for the system. There exist ports for the majority embedded architectures as PowerPC, x86 family, MIPS, SH-4, and the closely inter-related family of ARM, StrongARM and XScale CPUs. The most significative features are:

- Kernel only contains the scheduler, interprocess communication, interruption and timer managers.
- Process intercommunication is performed by send and wait for a reply. CPU transfers the control to the target process. This avoids empty waits.
- I/O operations (including file system and network operations) work through the above mechanisms.
- Support to symmetric multiprocessing.
- Support to strict priority-pre-emptive scheduling and adaptive partition scheduling (APS). It allows to guarantee a minimum CPU percentage for a task even though others may have higher priority.

4.17. VxWorks

VxWorks ***[VxWorks]*** is a proprietary operating system of Wind River of Alameda. It is specially designed for its use in embedded systems that require a deterministic performance including real-time, safety and security certification for different kind of industries. It is available for a wide range of architectures including Intel x86, Intel x86-64, MIPS, PowerPC, SH-4, and ARM architectures. It supports different configurations as asymmetric, symmetric or mixed multiprocessing. The main features of VxWorks are:

- Multitasking kernel with pre-emptive and round-robin scheduling and fast interrupt response.
- User-mode applications ("Real-Time Processes", or RTP) isolated from other usermode applications as well as the kernel via memory protection mechanisms.
- Support for a wide range of protocols as Bluetooth, USB, CAN protocols, Firewire IEEE 1394, BLE, L2CAP, Continua stack, health device profile, IPv6
- Support for different file systems: High Reliability File System (HRFS), FAT-based file system (DOSFS), Network File System (NFS), and TFFS.
- Modular architecture, each of the modules and layers can be updated independently.
- Multiple development and productivity tools offered by the company.
- VxWorks is used in multiple products of different market areas: aerospace and defence, automotive, industrial such as robots, consumer electronics, medical area and networking.

4.18. RT Linux

RTLinux ***[RTLinux]*** is a hard real-time operating system based on a Linux distribution. Due to hard-real time characteristic it is used to control robots and manufacturing plants. It is based in a microkernel that runs the entire Linux operating systems as a fully pre-emptive process. Its design is based on share the computing device between the real-time (basic kernel) and non-real-time operating system (Linux). From the programmer's point of view it looks like a small threaded environment for real-time tasks with the addition of standard Linux environment for non-critical tasks. That allows that the worst case time between the moment in which a hardware interrupt is detected by the processor and the moment an interrupt handler starts to execute is under 15 microseconds on RTLinux running on a generic x86. A RTLinux periodic task runs within 25 microseconds of its scheduled time on the same hardware. These times are hardware limited.

4.19. OpenWRT

OpenWRT ***[OpenWRT]*** is an embedded operating system specially designed for its implantation over routers, access point and networks devices. It is based on the Linux kernel optimized for constrained devices, being small enough to be stored in home routers. It is possible to add more functionalities due to existence of more than 3500 packages. Remarkable features are:

- Writable root file system, enabling users to add, remove or modify any file.
- Fully configuration of the entire hardware drivers.
- Support to IPv4 and IPv6 being completely configurable.
- Including routing support through iproute, Quagga, BIRD, and BABEL.
- Mesh networking support includes B.A.T.M.A.N., OLSR and IEEE 802.11s.
- Wireless functionality, the device can act as a wireless repeater, a wireless access point, a wireless bridge, a captive portal, or a combination of them.
- Support to wide range of network protocols as OpenVPN, DNS, DHCP, D-DNS, WDS, MQTT, SAMBA, NFS, FTP, PBX, and etcetera.

9. Languages and libraries (software)

In order to create programs to the systems we need programming languages, tools and frameworks to develop them. In next sections we summarize the most employed ones:

4.1. C/C++

A wide amount of projects for industrial applications and embedded computers are programmed in C/C++ or derived sub-languages. The main advantage of C/C++ is the possibility to design and implement the best relation about optimization and portability code with the minimum lines of code. This is important in critical or efficient applications. Also, as main features are the possibility to access to low level programming and the existence of standard libraries available for different architectures.

Embedded C is the ability to programme using these low level facilities of the language, that is, keep in mind the managing of bit operations, efficient code, inclusion of assembler code, etcetera.

4.2. Processing/Wiring

Processing/Wiring is the official programing language for the Arduino platform. Under the same name it is integrated an IDE and the own language. The language is close similar to Java and C++ simplified to avoid the complex aspects of these languages. Each program or library is called sketch and it is possible to combine different sketches to obtain bigger programs.

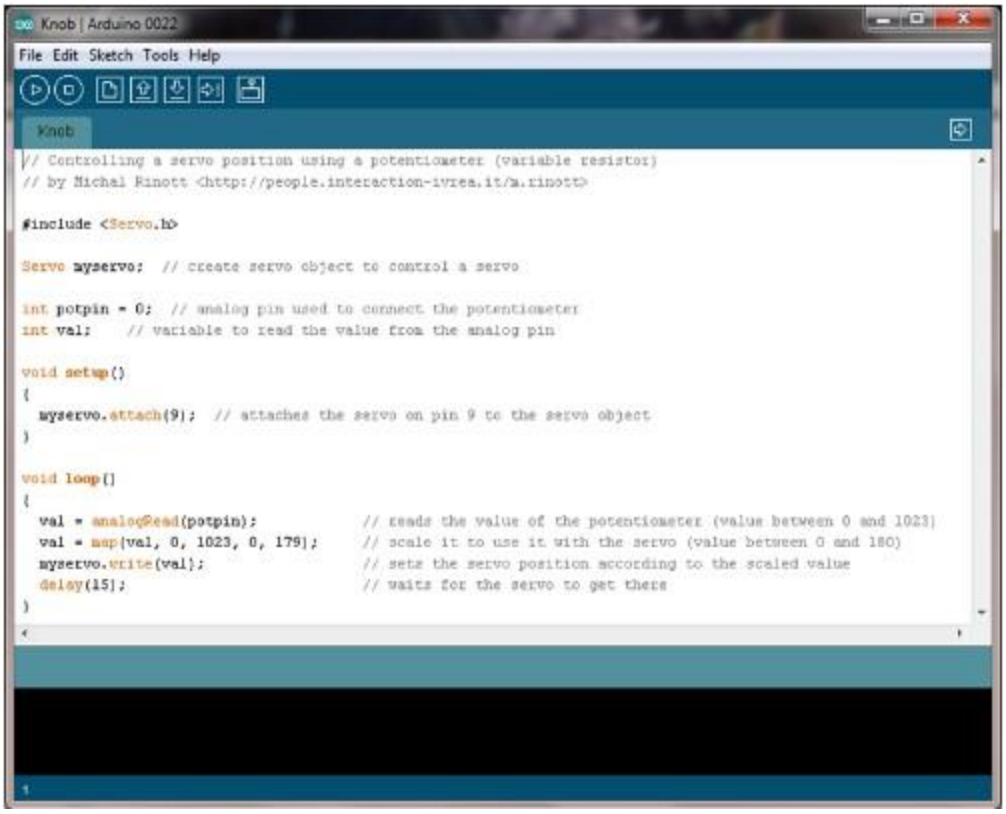

Figure 109. Processing/Wiring IDE and language

4.3. Python

Python is a scripting language that is the "standard" for Raspberry Pi (the name of the architecture comes from Raspberry Py-thon). Its main advantage is that it has a clear structure due to its own syntax rules. It produces an extremely readable code. It is built under the next rules:

- Beautiful is better than ugly.
- Explicit is better than implicit. Simple is better than complex.
- Complex is better than complicated. Readability counts.

Due its popularity there exist different libraries for accessing to the hardware, in particular to the GPIO (General Purpose Input Output). Although it is an interpreter its code is very efficient.

```python
def quadrato(*numeri):
        c = [str(x**2) for x in numeri]
        print ' ; '.join(c)

def divisore(num, den):
        try:
                if den == 1:
                        return num
                else:
                        return float(num)/den
        except ZeroDivisionError:
                print 'Errore. Divisione per zero!'
```

Figure 110. Python program example

4.4. LAMP (Linux, Apache, MySQL, PHP)

Due to there exist embedded computers that offer some services or web interfaces for its configuration, the LAMP framework is one of the most common options to be used. The LAMP framework is composed by:

- Linux: using a Linux-based operating system in the device.
- Apache: that is a web server.
- MySQL: that is a SQL database.
- PHP: that is a scripting language that offers a wide range of libraries easing the fast development of applications.

The popularity of the use of these set of programs is due to their popularity and free cost. This software comes pre-installed in the majority of Linux distributions.

4.5. Lua

Lua is an interpreted language closer to Python or Perl but with the advantage of it can be extended with new functionalities. Programs are compiled to bytecode and later executed by the Lua virtual machine. It only defines a basic set of types and data structures and depending on the application new functions and extensions are defined. Other particular characteristic is that the bytecode is extremely efficient. Finally it can embed C code.

```lua
math_mod = require( "Module:Math" );
globalFrame = nil

coordinates = {};

--[[ Helper function, replacement for {{coord/display/title}} ]]
function displaytitle (s)
    local l = "[[Geographic coordinate system|Coordinates]]: " .. s
    local co = '<span id="coordinates">' .. l .. '</span>';
    return '<span style="font-size: small;">' .. co .. '</span>';
end

--[[ Helper function, Replacement for {{coord/display/inline}} ]]
function displayinline (s)
    return s
end

--[[ Helper function, used in detecting DMS formatting ]]
local dmsTest = function(first, second)
    local concatenated = first:upper() .. second:upper();

    if concatenated == "NE" or concatenated == "NW" or concatenated == "SE" or concatenated == "SW" or
        concatenated == "EN" or concatenated == "WN" or concatenated == "ES" or concatenated == "WS" then
        return true;
    end
    return false;
end
```

Figure 111. Lua program example

4.1. ADA

Ada is a structured language especially targeted for embedded and real-time systems keeping in mind safety and maintainability by using the compiler to find the maximum amount of errors instead of runtime errors. Ada is extended from Pascal syntaxis. Main characteristics of the language are:

- Ada syntax minimizes the choices or ways to define or perform operations. There is only one way to do one thing.
- Ada is based on modularity and is well-suited for the development of large software systems. It is based on the concept of packages. Packages can be compiled before their implementation in order to detect problems during the design phase.
- Existence of large number of compile-time checks to avoid undetectable bugs during run-time. Also offers support for run-time checks to protect against access to unallocated memory, buffer overflow, range violations, etcetera.
- Efficient dynamic memory allocation and garbage collector.

4.1. Assembler

Assembler language is closely related to the hardware. Its commands, operators and tools depends entirely of the processor of the system. This language is the final option when does not exist a solution in a high-level language or it is needed a very efficient and optimized code.

4.1. Forth

Forth is an imperative stack-based programming language. Forth is used in the Open Firmware boot loader, space applications and embedded systems. It is very efficient and it enables the possibility to define new commands and program reflection (changing the own program structure during execution).

4.1. Hardware Description Languages

Hardware Description Language are used to design, describe and define the behaviour of electronic circuits, in special digital logic circuits. They allow to define a formal and precise description of electronic circuits, enabling the possibility to perform automated analysis and simulation test. Furthermore, some languages could be used by industrial machinery in order to create the integrated circuits of these designs. HDLs form an integral part of electronic design automation (EDA) systems, especially for complex circuits, such as applicationspecific integrated circuits, microprocessors, and programmable logic devices.

A hardware description languages is close to computer programming languages, that is a textual description using expressions, statements, directives and control structures. An additional feature is the inclusion of the notion of time due to the importance of how latency, delays, threshold, etcetera can affect to the electronic components.

There exist a wide range of HDL languages, but two are the most common and set the basis for the rest:

- Verilog: that is a standardized language by IEEE 1364 used to model analogic and digital electronic systems. The language is similar to the C programming language. It has control flow keywords and includes different variable types definition. It is based on the definition of modules that are set in a hierarchy.

Modules communicate with other modules by means of a declared interface (input and outputs).

- VHDL: that is a language for the description of digital systems as fieldprogrammable gate arrays and integrated circuits. Also, it is used as general purpose parallel programming language. The language is close to Ada and it is standardized as IEEE 1076.

Other HDLs are:

- Advanced Boolean Expression Language (ABEL).
- Altera Hardware Description Language (AHDL).
- AHPL.
- Bluespec.
- HML (Hardware ML).
- PALASM.
- SystemVerilog. THDL++.

4.1. LabVIEW

Labview ***[LabView]*** is a system-design platform based on a graphical language called G for design and definition of hardware and software for control automation and embedded systems. The G language is a dataflow programming language in which execution is defined by the structure of different graphical blocks connected by wires. Wires propagate variables and values enabling that multiple nodes receive these values (parallel execution). The main advantage of Labview is that eases the development of programs by non-programmers but it can be used by expert programmers to build complex systems.

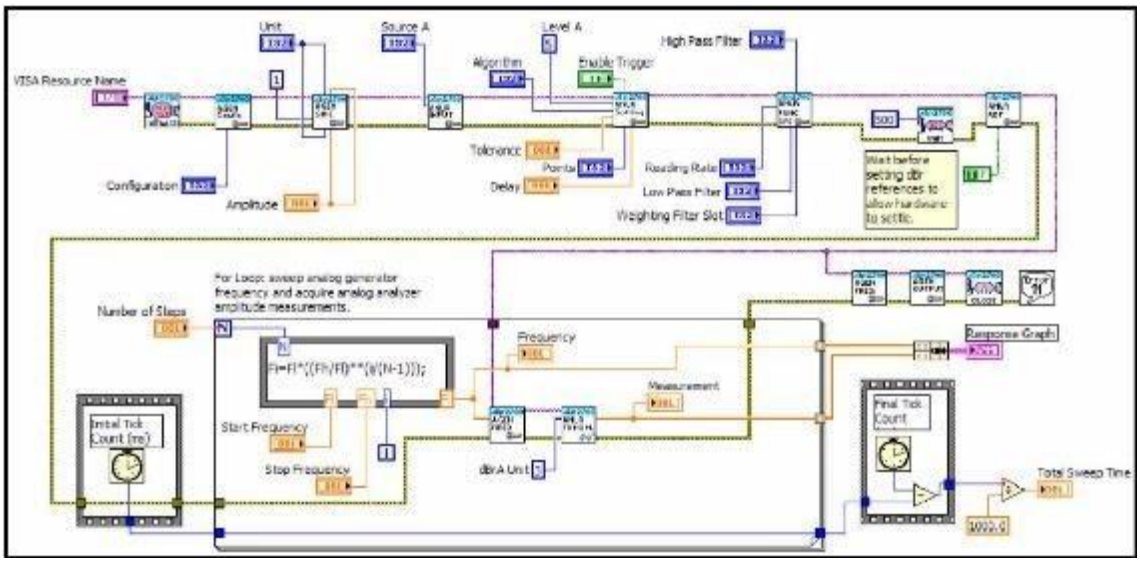

Figure 112. LabView Example

10. REFERENCES

[cyberphysicalsystems] cyber-physical systems organization web site. http://cyberphysicalsystems.org

[CPSWikipedia] Wikipedia entry. https://en.wikipedia.org/wiki/Cyber-physical_system

[iec] IEC official site. http://www.iec.ch

[MIL-STD-810] Information about the normative. http://everyspec.com/MIL-STD/MILSTD-0800-0899/MIL-STD-810G_12306/

[MIL-STD-461] Information about the normative: http://www.tscm.com/MIL-STD461E.PDF

[MIL-S-901] Information about the normative: http://www.everyspec.com/MIL-SPECS/MIL-SPECS-MIL-S/MIL-S-901D_14581/

[IEEE1613] Information about the standard: http://standards.ieee.org/findstds/standard/1613a-2011.html

[IntrinsicSafety] Information about the normative: http://www.ameradio.com/systems/intrinsic_safety.html

[TEMPEST] Information about the normative: http://www.nsa.gov/ia/industry/tempest.cfm

[ATEX] Information about the directive: http://www.hse.gov.uk/fireandexplosion/zoning.pdf

[EN62262] Information about the standard: http://www.techstreet.com/cgi-bin/detail?product_id=1117931

[EN50155] Information about the standard: http://shop.bsigroup.com/ProductDetail/?pid=000000000030228803 ***[NEMA]***

NEMA Web page: http://www.nema.org/

[IEEE1156] Information about the standard: https://standards.ieee.org/findstds/standard/1156.1-1993.html

[AMD] Official web site: http://www.amd.com

[TexasInstruments] Official web site: http://www.ti.com

[NativeInstruments] Official web site: http://www.ni.com

[Artila] Official web site: http://www.artila.com/en

[Advantech] Official web site: http://www2.advantech.com/

[ADLink] Official web site: http://adlinktech.com

[EVOC] Official web site: http://www.evoc.com

[Acrosser] Official web site: http://www.acrosser.com

[Addi-data] Official web site: http://addi-data.com

[ESA-Automation] Official web site: http://www.esa-automation.com

[Mosaic] Official web site: http://mosaic-industries.com

[Unitronics] Official web site: http://www.unitronics.com

[iBase] Official web site: http://www.ibase.com

[ICNexus] Official web site: http://www.icnexus.com

[IPC2U] Official web site: http://www.ipc2u.com

[OMRON] Official web site: http://www.omron.com

[Sinetic] Official web site: http://www.sinetic.com

[Toradex] Official web site: http://www.toradex.com

[VTIInstruments] Official web site: http://www.vtiinstruments.com/Home.aspx

[Gateworks] Official web site: http://www.gateworks.com/

[IndustrialShields] Official web site: http://www.industrialshields.com

[Siemens] Official web site: http://www.siemens.com/

[Schneider] Official web site: http://www.schneider-electric.com/ww/en/

[FSNet] Official web site: http://www.fs-net.de/
[TechnologicSystems] Official web site: https://www.embeddedarm.com
[TQGroup] Official web site: http://www.tq-group.com/
[Digi] Official web site: http://www.digi.com
[ForLinx] Official web site: http://www.forlinx.net
[MPL] Official web site: http://www.mpl.ch
[Myirtech] Official web site: http://www.myirtech.com.tw
[EuroTech] Official web site: http://www.eurotech.com
[Embedian] Official web site: http://www.embedian.com
[SysLogic] Official web site: http://www.syslogic.de
[Lanner] Official web site: http://www.lannerinc.com
[Seco] Official web site: http://www.seco.com
[Libelium] Official web site: http://www.libelium.com
[Abaco] Official web site: http://www.abaco.com
[Aitech] Official web site: http://www.rugged.com
[CurtissWright] Official web site: https://www.curtisswrightds.com/
[Emac] Official web site: https://www.emacinc.com
[OrionTechnologies] Official web site: http://www.oriontechnologies.com
[XES] Official web site: http://www.xes-inc.com/
[MercurySystems] Official web site: http://mrcy.com

[Odroid] Official web site: http://www.hardkernel.com/main/main.php
[CubieTech] Official web site: http://www.cubietech.com
[BeagleBone] Official web site: http://beagleboard.org/bone
[SeedStudio] Official web site: http://www.seeedstudio.com/
[IntelGalileo] Product information: https://www.arduino.cc/en/ArduinoCertified/IntelGalileo
[IntelEdison] Product information: http://www.intel.la/content/www/xl/es/do-ityourself/edison.html
[RaspberryPi] Product information: https://www.raspberrypi.org/
[TouchBoard] Product information: http://www.bareconductive.com/shop/touch-board/
[Trinket] Product information: https://www.adafruit.com/products/1500
[NextThingCHIP] Official web site: http://nextthing.co/pages/chip
[GizmoSphere] Official web site: http://www.gizmosphere.org
[RFID] Official web site: http://rainrfid.org
[WiFiAlliance] Official web site: http://www.wi-fi.org
[Bluetooth] Official web site: http://www.bluetooth.com
[ArdOS] Official web site: https://bitbucket.org/ctank/ardos-ide/wiki/Home
[DuinOS] Official web site: https://github.com/DuinOS/DuinOS
[FemtoOS] Official web site: https://www.femtoos.org
[RTuinOS] Official web site: https://github.com/PeterVranken/RTuinOS
[Raspbian] Official web site: https://www.raspbian.org
[Windows10IoT] Official web site: https://dev.windows.com/es-es/iot

[ArchLinuxARM] Official web site: http://archlinuxarm.org
[TinyOS] Official web site: http://www.tinyos.net
[Contiki] Official web site: http://www.contiki-os.org
[LiteOS] Official web site: http://www.liteos.net
[BertOS] Official web site: http://github.com/develersrl/bertos
[NetBSD] Official web site: https://www.netbsd.org/
[MicroCOSII] Official web site: https://www.micrium.com/rtos/ucosii/overview/
[QNX] Official web site: http://www.qnx.com/products/neutrino-rtos/index.html
[VxWorks] Official web site: http://windriver.com/products/vxworks/
[RTLinux] Official web site: https://rt.wiki.kernel.org/index.php/Main_Page
[OpenWRT] Official web site: https://openwrt.org/ ***[LabView]***
Official web site: http://www.ni.com/labview/

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